



The Duckietown Book

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The last version of this book and other documents are available at the URL
<http://book.duckietown.org/>

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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:

- **NCTU 2016** - Prof. Nick Wang;
- **RPI 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:

- RPI (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

First steps

3.1. How to get started

If you are an instructor, please jump to [Section 3.2](#).

If you are a self-guided learner, please jump to [Section 3.3](#).

If you are a company, and interested in working with Duckietown, please jump to [Section 3.4](#).

3.2. Duckietown for instructors

TODO: to write

3.3. Duckietown for self-guided learners

TODO: to write

3.4. Introduction for companies

TODO: to write

3.5. How to keep in touch

TODO: add link to Facebook

TODO: add link to Mailing list

TODO: add link to Slack?

3.6. 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...

3.7. 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.

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. 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.

CHAPTER 4

Accounts

4.1. 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.

4.2. 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.

PART 2

Duckumentation documentation

..

CHAPTER 5

Contributing to the documentation

5.1. 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.

5.2. 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.

5.3. 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.)

5.4. 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.

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
$ 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
```

5.5. 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`.

5.6. 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.

5.7. 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.

5.8. *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 out 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.

5.9. *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 nodejs

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

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.

6.1. Markdown

The Duckiebook is written in a Markdown dialect.

→ [A tutorial on Markdown.](#)

6.2. 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.

TODO: other LaTeX features supported

6.3. 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.

6.4. 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.

6.5. Character escapes

Use the string “`\$`” 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 1](#).

TABLE 1. SYMBOLS TO ESCAPE

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

6.6. 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>.
```

6.7. 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”.

6.8. 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 9. Caption of big figure

6.9. 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 2. 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 3. USING CLASS="LABELS-COL1"

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

TABLE 4. USING CLASS="LABELS-ROW1"

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

6.10. Linking to documentation from inside and outside the 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 5).

TABLE 5. SYNTAX FOR REFERRING TO SECTIONS.

See [](#establishing).

See Subsection 6.10.1

See .

See Establishing names of headers.

See .

See 6.10.1.

See .

See Subsection 6.10.1 - 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 108.2](#).

6.11. 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:

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

For example, this code:

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

produces this result:



Figure 10. 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).



6.12. 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].

CHAPTER 7

Documentation style guide

This chapter describes the conventions for writing the technical documentation.

7.1. 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.

7.2. 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.
 - ✗ “Edit the `~/.ssh/config` file using `vi`.”
 - ✓ “Edit the `~/.ssh/config` file using `vi`.”
- `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.

7.3. 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
```

7.4. Frequently misspelled words

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

7.5. 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.)

7.6. 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 8

Knowledge graph

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

8.1. Formalization

1) Atoms

Definition 1. (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 2. (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 8.1.2.

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.

8.2. 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 6).
- A human-readable title.
- A human-readable summary (1 short paragraph).

TABLE 6. STATUS CODES

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

8.3. 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 2. `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 3. `calibration.it.md`

8.4. 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 7. 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 `rostopic`, see [](#rostopic).

See also

See also: If you are interested in feature detection, you might want to learn about [SIFT](#SIFT).

8.5. How to describe modules



TODO: Define a micro-format for this.

PART 3

Operation manual - Duckiebot



CHAPTER 9

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+wjd` or `C1` Duckiebot.

9.1. 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+wjd`, plus LEDs and bumpers.

9.2. 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 corssing an intersection).

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

CHAPTER 10

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 169 + Shipping Fees (minimal configuration C0) - Time: 15 days (average shipping for cheapest choice of components)

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

Next Steps: - After receiving these components, you are ready to do some [soldering](#) before [assembling](#) your C0 or C0+wd 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 (?)

10.1. Bill of materials



TABLE 8. BILL OF MATERIALS

Chassis	USD 20
Camera with 160-FOV Fisheye Lens	USD 22
Camera Mount	USD 8.50
300mm Camera Cable	USD 2
Raspberry Pi 3 - Model B	USD 35
Heat Sinks	USD 5
Power supply for Raspberry Pi	USD 7.50
16 GB Class 10 MicroSD Card	USD 10
Mirco SD card reader	USD 6
Stepper Motor HAT	USD 22.50
Stacking Header	USD 2.50/piece
Battery	USD 20
16 Nylon Standoffs (M2.5 12mm F 6mm M	USD 0.05/piece
4 Nylon Hex Nuts (M2.5)	USD 0.02/piece
4 Nylon Screws (M2.5x10)	USD 0.05/piece
2 Zip Ties (300x5mm)	USD 9
Wireless Adapter (5 GHz) (C0+w)	USD 20
Joypad (C0+j)	USD 10.50
Tiny 32GB USB Flash Drive (C0+d)	USD 12.50
Total for C0 configuration	USD 159
Total for C0+w configuration	USD 179
Total for C0+j configuration	USD 169.50
Total for C0+d configuration	USD 171.50
Total for C0+wd configuration	USD 212

TODO: modify to account for new USB to wires power solution.

10.2. Chassis

We selected the Magician Chassis as the basic chassis for the robot ([Figure 11](#)).

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.

The price for this in the US is about USD 15-30.



Figure 11. The Magician Chassis

10.3. Raspberry Pi 3 - Model B

The Raspberry Pi is the central computer of the Duckiebot. Duckiebots use Model B ([Figure 12](#)) (A1.2GHz 64-bit quad-core ARMv8 CPU, 1GB RAM), a small but powerful computer.



Figure 12. 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 13](#)).



Figure 13. 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 14](#). 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 14. The Heat Sinks

3) Class 10 MicroSD Card

The MicroSD card ([Figure 15](#)) is the hard disk of the Raspberry Pi. 16 Gigabytes of capacity are sufficient for the system image.



Figure 15. The MicroSD card

4) Mirco SD card reader

A microSD card reader ([Figure 16](#)) 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 16. The Mirco SD card reader

10.4. 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 17).



Figure 17. The Camera with Fisheye Lens

1) Camera Mount

The camera mount (Figure 18) serves to keep the camera looking forward at the right angle to the road (looking slightly down). The front cover is not essential.

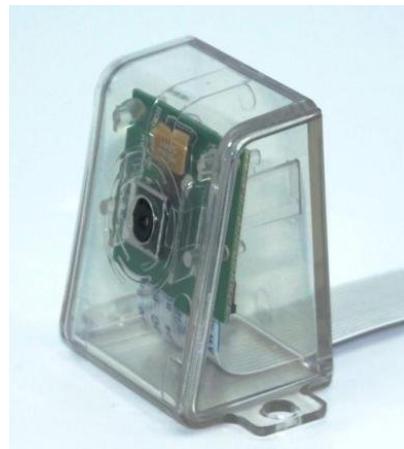


Figure 18. The Camera Mount

2) 300mm Camera Cable

A longer (300 mm) camera cable [Figure 19](#) make assembling the Duckiebot easier, allowing for more freedom in the relative positioning of camera and computational stack.

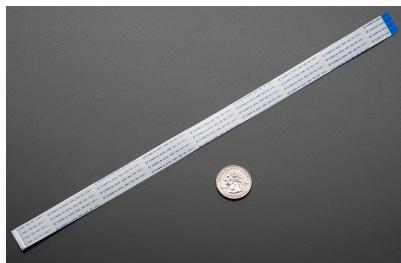


Figure 19. A 300 mm camera cable for the Raspberry Pi

10.5. DC Stepper Motor HAT

We use the DC Stepper motor HAT ([Figure 26](#)) to control the DC motors that drive the wheels. This item will require [soldering](#) to be functional.

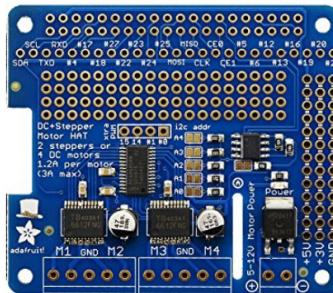


Figure 20. The Stepper Motor HAT

1) Stacking Headers

We use a long 20x2 stacking header ([Figure 21](#)) to connect the Raspberry Pi with the DC Stepper Motor HAT. This item will require [soldering](#) to be functional.



Figure 21. The Stacking Headers

10.6. Battery

The battery ([Figure 22](#)) 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 (USD 20).



Figure 22. The Battery

10.7. 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.

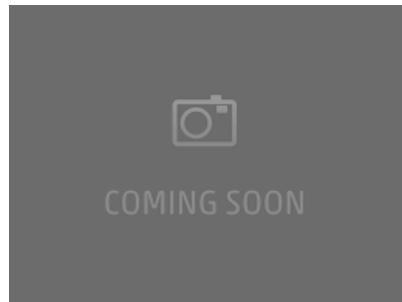


Figure 23. Standoffs, Nuts and Screws

10.8. Zip Tie

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



Figure 24. The zip ties

10.9. Configuration C0-w

1) Wireless Adapter (5 GHz)

The Edimax AC1200 EW-7822ULC 5 GHz WiFi adapter ([Figure 25](#)) boosts the connectivity of the Duckiebot, especially useful in busy Duckietowns (e.g., classroom).



Figure 25. The Edimax AC1200 EW-7822ULC wifi adapter

10.10. 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 26](#)) does not include batteries (required: 2 AA 1.5V).



Figure 26. A Wireless Joypad

TODO: Add figure with 2 AA batteries

10.11. Configuration C0-d

1) Tiny 32GB USB Flash Drive

In configuration C0+d, the Duckiebot is equipped with a “external” hard drive ([Figure 27](#)). 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 27. The Tiny 32GB USB Flash Drive

CHAPTER 11

Soldering boards for C0



Assigned to: Shiyeng

Resources necessary:

Requires: - Duckiebot `C0+wjd` parts. The acquisition process is explained in [Chapter 10](#). The configurations are described in [Chapter 9](#).

Requires: - Time: ??? minutes

Results:

- ...

TODO: finish above

CHAPTER 12

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 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 9](#).

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 - a pair of scissors - a multimeter (only if you are not purchasing the [suggested components](#))

Requires: - Time: 5 minutes

Results: - One male USB-A to wires power cable

12.1. 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 10](#), you can use the longer USB cable contained inside the battery package ([Figure 28](#)), which will be used as an example in these instructions.



Figure 28. The two USB cables in the suggested battery pack.

Put the shorter cable back in the box, and open the longer cable ([Figure 29](#))



Figure 29. Take the longer cable, and put the shorter on back in the box.

12.2. Step 2: Cut the cable

Make sure the USB cable is *not* plugged in to anything. Take the scissors and cut it ([Figure 30](#)) at the desired length from the USB-A port.

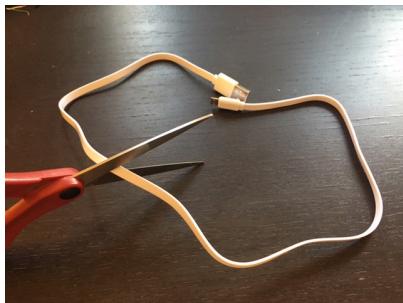


Figure 30. Cut the USB cable using the scissors.

The cut will look like in [Figure 31](#).



Figure 31. A cut USB cable.

12.3. 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 32](#).



Figure 32. Stripping the external layer of the USB cable.

After removing the external plastic, you will see four wires: black, green, white and red ([Figure 33](#)).

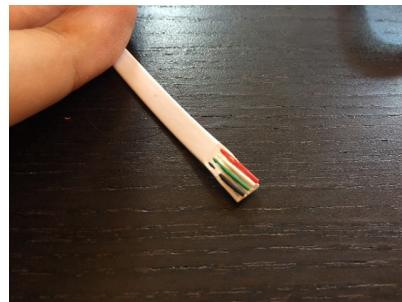


Figure 33. Under the hood of a USB-A cable.

Once the bottom part of the external cable is removed, you will have isolated the four wires ([Figure 34](#)).

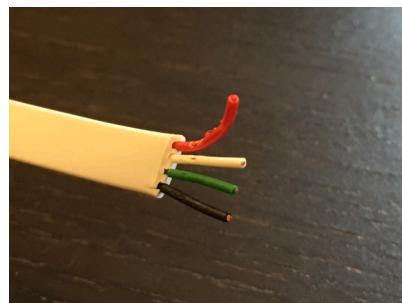


Figure 34. The four wires inside a USB-A cable.

12.4. Step 3: Strip the wires

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 35](#)).



Figure 35. 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.

12.5. 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 which the power wires are, continue reading here.

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 36](#)).



Figure 36. Finding which two wires are for power.

12.6. 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 11](#).

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 37](#)).

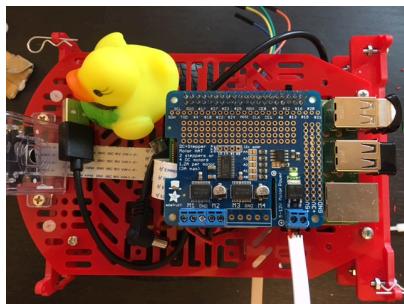


Figure 37. Connnect the power wires to the DC motor HAT

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

CHAPTER 13

Assembling the Duckiebot C0



Assigned to: Shiying

Requires: - Duckiebot C0+wd parts. The acquisition process is explained in [Chapter 10](#).

- Having soldered the C0+wd parts. The soldering process is explained in [Chapter 11](#).
- Having prepared the power cable. The power cable preparation is explained in [Chapter 12](#).
- Time: about ??? minutes.

TODO: estimate time.

Results:

- An assembled Duckiebot in configuration C0+wd.

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

CHAPTER 14

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.

14.1. 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
```

14.2. Burn the image to an SD card

Next, burn the image on to the SD card.

- This procedure is explained in [Section 93.2](#).

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:

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

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

14.3. Raspberry Pi Config

The Raspberry Pi is not accessible by SSH by default.

Run `raspi-config`:

```
raspberry $ 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

14.4. Install packages

Install these packages.

Etckeeper:

```
raspberry $ sudo apt install etckeeper
```

Editors / shells:

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

Git:

```
raspberry $ 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
```

14.5. 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
```

14.6. Install ROS



Install ROS.

→ The procedure is given in [Section 105.1](#).

14.7. 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
}
```

14.8. 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
uuid=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:A0 - to change
mac-address-blacklist=
mac-address-randomization=0
mode=ap
seen-bssids=
ssid=duckiebot-not-configured

[ipv4]
dns-search=
method=shared

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

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

14.9. SSH server config

This enables the SSH server:

```
$ sudo systemctl enable ssh
```

14.10. 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

14.11. 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
```

14.12. Clean up

You can use the command `dpigs` 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.

14.13. 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 95.3](#).

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
```

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
```

14.14. 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.)

14.15. 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 93.2](#); 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 93.3](#).

14.16. 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: I
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 103.1](#).

CHAPTER 15

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 .

TODO: estimate time

Results:

- A laptop ready to be used for Duckietown.

15.1. 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.

15.2. 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

15.3. Install ROS

Install ROS on your laptop.

- The procedure is given in [Section 105.1](#).

15.4. 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.

15.5. 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 5.4](#).

15.6. Passwordless sudo

Set up passwordless `sudo`.

- This procedure is described in [Section 14.11](#).

15.7. SSH and Git setup

1) Basic SSH config

Do the basic SSH config.

- The procedure is documented in [Section 95.3](#).

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 95.5](#).

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

Add the public key to your Github account.

- The procedure is documented in [Section 104.3](#).

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 102.3](#).

CHAPTER 16

Duckiebot Initialization



Assigned to: Andrea

Requires: An SD card of dimensions at least 32 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 13.

Result:

- A Duckiebot that is ready to use.

What does it mean “ready to use”?

16.1. Acquire and burn the image



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

<https://www.dropbox.com/s/lp4am7erdd9e53r/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
2ea79b0fc6353361063c89977417fc5e8fde70611e8afa5cbf2d3a166d57e8cf 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 93.2](#).

16.2. 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

16.3. 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.

16.4. 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  
...
```

16.5. 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 101](#) for an introduction to Byobu.

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

16.6. (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 AABBCCDDEEFFGG unassociated Nickname:"rtl18822bu"
...
lo      no wireless extensions.

enx827eb1f81a4  no wireless extensions.

wlan1    IEEE 802.11bgn  ESSID:"duckietown"
...
...
```

Make note of the name `wlan0 ABBCCDDEEFFGG`.

Look up the MAC address using the command:



```
$ ifconfig wlan0 ABBCCDDEEFFGG
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 “`wlan0 ABBCCDDEEFFGG`”.
- 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.

16.7. 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.

16.8. 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
```

16.9. 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.

16.10. 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
```

16.11. 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 size of your SD card.

16.12. 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 andrea`

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 95.3](#).

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 95.5](#).

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

Add the public key to your Github account.

- The procedure is documented in [Section 104.3](#).

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



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

4) Local Git configuration

- This procedure is in [Section 102.3](#).

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 95.6](#). 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 roboticsists and going crazy.

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

16.13. 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`.

16.14. 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 97.1.1](#).

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 17

Software setup and RC remote control



Assigned to: Andrea

Requires: Laptop configured, according to [Chapter 15](#).

Requires: You have configured the Duckiebot. The procedure is documented in [Chapter 16](#).

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 104](#).

Results:

- You can run the joystick demo.

17.1. 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 104](#).

Symptom: Other weird errors.

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

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

17.2. 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 105.6](#).

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

17.3. Add your vehicle to the scuderia file

Add your vehicle to the scuderia file.

→ See [Section 108.2](#).

17.4. 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:



```
$ 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`:



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

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

→ Consult again [Section 16.12](#).

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



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

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

17.5. Run the joystick demo

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



```
$ 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 17.4](#).

17.6. 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 18

Reading from the camera



Requires: You have configured the Duckiebot. The procedure is documented in [Chapter 16](#).

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

TODO: put reference

Results:

- You know that the camera works under ROS.

18.1. Check the camera hardware



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

- The procedure is documented in [Section 16.14](#).

18.2. Create two windows



On the laptop, create two Byobu windows.

- A quick reference about Byobu commands is in [Chapter 101](#).

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.

18.3. 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`:

 \$ roslaunch 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 105.3](#).

18.4. 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 105.5](#).

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 20](#), you will learn how to visualize the image stream on the laptop using `rviz`.

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

CHAPTER 19

RC control launched remotely

Assigned to: Andrea

Requires: You can run the joystick demo from the Raspberry Pi. The procedure is documented in [Chapter 17](#).

Results:

- You can run the joystick demo from your laptop.

19.1. 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

19.2. 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 17.1](#).

Then, you should build the repository.

- This procedure is documented in [Section 17.2](#).

19.3. 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 17.3](#).

19.4. 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
\$ rosrun 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 `rosrun`, see [Section 105.3](#).

19.5. 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 `rosrun` was executed to stop all the nodes launched by the launch file.

* For more information about `rqt_console`, see [Section 105.2](#).

19.6. Troubleshooting



Symptom: `rosrun` 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 95.3](#).

CHAPTER 20

RC+camera remotely

Assigned to: Andrea

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

Requires: You can read the camera data from ROS. The procedure is documented in [Chapter 18](#).

Requires: You know how to get around in Byobu. You can find the Byobu tutorial in [Chapter 101](#).

Results:

- You can run the joystick demo from your laptop and see the camera image on the laptop.

20.1. Assumptions

We are assuming that the joystick demo in [Chapter 19](#) worked.

We are assuming that the procedure in [Chapter 18](#) succeeded.

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

20.2. Terminal setup

On the laptop, this time create four Byobu windows.

→ A quick reference about Byobu commands is in [Chapter 101](#).

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

20.3. First window: launch the joystick demo

In the first window, launch the joystick remotely using the same procedure in [Section 19.4](#).



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

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

20.4. 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.

20.5. 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
```

20.6. 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 105.4](#).

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.

20.7. 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 21

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.

Results:

- You will know about some useful shortcuts.

21.1. 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.

21.2. 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 22

Wheel calibration



| Assigned to: Andrea

CHAPTER 23

Camera calibration

..

CHAPTER 24

Taking a log



| Assigned to: Andrea

PART 4

Operation manual - Duckietowns

..

CHAPTER 25

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 29](#) 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: [Assembly](#) a Duckietown.

TODO: Figure out costs

25.1. Bill of materials



TABLE 9. BILL OF MATERIALS FOR DUCKIETOWN

Duckies	USD 17/100 pieces
Floor Mats	USD 37.5/6 pieces (24 sqft)
Duct tape - Red	USD 8.50/roll
Duct tape - White	USD 8.50/roll
Duct tape - Yellow	USD 8/roll
Traffic signs	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

25.2. Duckies



Duckies ([Figure 38](#)) are essential yet non functional.

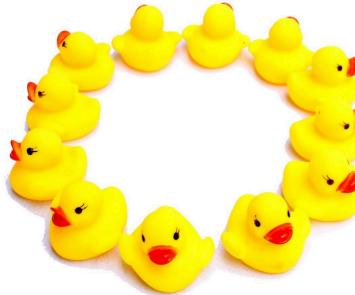


Figure 38. The Duckies

25.3. Floor Mats

The floor mats ([Figure 39](#)) 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 39. 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 29](#).

25.4. Duck Tape

We use duck (duct) tape of different colors ([Figure 40](#)) 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 40. The Duck Tapes

To verify how much tape you need for each road segment type, see [Chapter 29](#).



25.5. Traffic Signs

Traffic signs (Figure 41) inform Duckiebots on the map of Duckietown, allowing them to make driving decisions.



Figure 41. The Signs

Depending on the chose road topography, the number of necessary road signal will vary. To design your Duckietown, see [Chapter 29](#).

CHAPTER 26

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 29](#).

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 - Time: ?? days (average shipping time)

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

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

TODO: Estimate time and costs

26.1. Bill of materials

TABLE 10. BILL OF MATERIALS FOR TRAFFIC LIGHT

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

TODO: Complete table

26.2. Raspberry Pi



(Figure 42) are essential yet non functional.

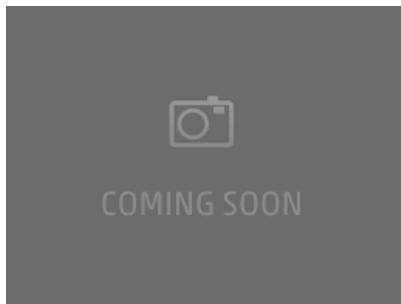


Figure 42. The placeholder

CHAPTER 27
Duckietown Assembly

• •

| Assigned to: Shiying

CHAPTER 28

Traffic lights Assembly

| Assigned to: Shiying



CHAPTER 29

The Duckietown specification

| Assigned to: Liam?

29.1. Topology

1) Topology constraints

29.2. Signs placement

PART 5

Operation manual - Duckiebot with LEDs



CHAPTER 30

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 9](#).

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.

30.1. Bill of materials



TABLE 11. BILL OF MATERIALS

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

30.2. LEDs

The Duckiebot is equipped with 5 RGB LEDs (Figure 43). 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.

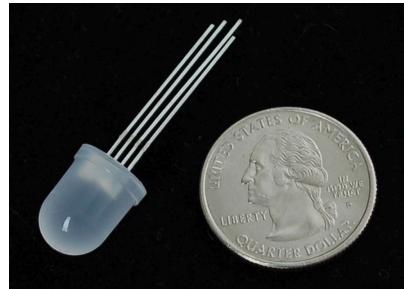


Figure 43. The RGB LEDs

1) LED HAT

The LED HAT (Figure 44) 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 designed 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.

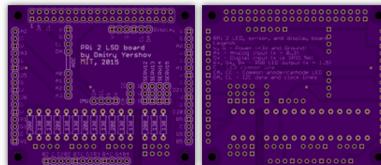


Figure 44. The LED HAT

2) PWM/Servo HAT

The PWM/Servo HAT (Figure 45) 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 45. 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 46](#)).



Figure 46. 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 47](#)) to power the DC Stepper Motor HAT from the PWM/Servo HAT.

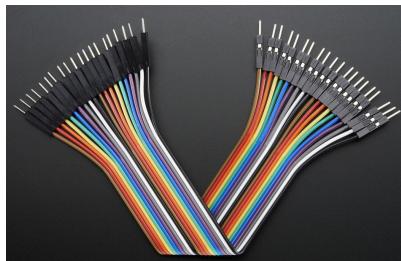


Figure 47. Premier Male-Male Jumper Wires

5) Female-Female Jumper Wires

20 Female-Female Jumper Wires ([Figure 48](#)) are necessary to connect 5 LEDs to the LED HAT.

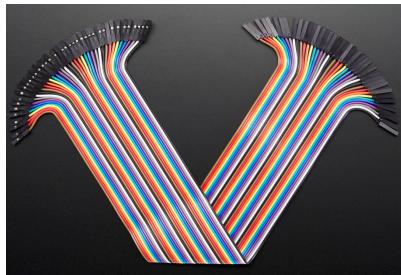


Figure 48. Premier Female-Female Jumper Wires

30.3. 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

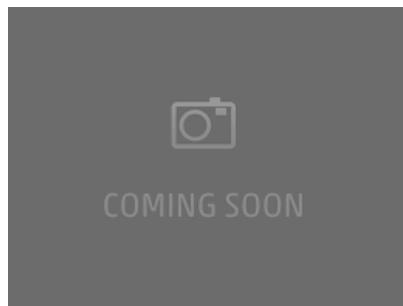


Figure 49. The Bumpers

30.4. 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](#).

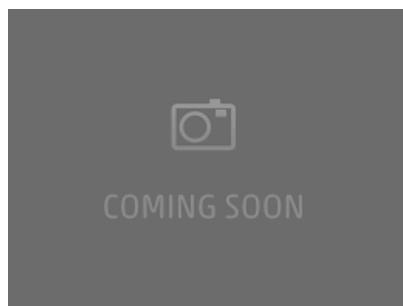


Figure 50. The Headers

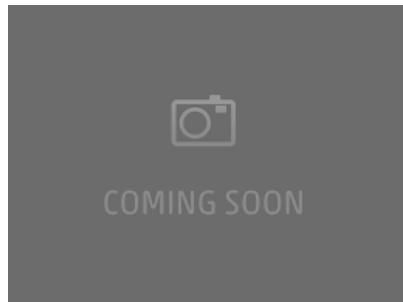


Figure 51. The Resistors

TODO: Missing figures.

CHAPTER 31

Soldering boards for C1



Assigned to: Shiyeng

Resources necessary:

Requires: - Duckiebot C1 parts. The acquisition process is explained in [Chapter 30](#).
The configurations are described in [Chapter 9](#).

Requires: - Time: ??? minutes

Results:

- ...

TODO: finish above

CHAPTER 32

Assembling the Duckiebot C1



Assigned to: Shiying

Requires: Duckiebot c1 parts. The acquisition process is explained in [Chapter 30](#).

Requires: Soldering c1 parts. The soldering process is explained in [Chapter 31](#).

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 33

C1 (LEDs) setup



| Assigned to: Andrea

PART 6

Theory chapters

..

These are the theory chapters.

CHAPTER 34

Chapter template



| Assigned to: Jacopo

CHAPTER 35

Symbols and conventions

Assigned to: Andrea

35.1. 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 .

35.2. Table of symbols

Here are some useful symbols.

TABLE 12. SPACES

command	result	
\SOthree	$\mathbf{SO}(3)$	Rotation matrices
\SEthree	$\mathbf{SE}(3)$	Euclidean group
\SEtwo	$\mathbf{SE}(2)$	Euclidean group
\setwo	$\mathbf{se}(2)$	Euclidean group algebra

States and poses:

TABLE 13. POSES AND STATES

command	result	
\pose	$\mathbf{q}_t \in \mathbf{SE}(2)$	Pose of the robot in the plane
\state_t \in \statesp	$\mathbf{x}_t \in \mathcal{X}$	System state (includes the pose, and everything else)

CHAPTER 36

Linear algebra



| Assigned to: Jacopo

CHAPTER 37

Probability basics



| Assigned to: Liam?

CHAPTER 38

Dynamics

| Assigned to: Jacopo

CHAPTER 39

Autonomy overview

| Assigned to: Liam

39.1. Perception, planning, control

CHAPTER 40**Autonomy architectures**

Assigned to: Andrea

40.1. Contracts

API: Types, messages
Latency, frequency
computation
semantics
reliability / probability



CHAPTER 41

Representations

Assigned to: Matt

Discuss:

- Introduction to the notion of *state* as a sufficient statistic that represents the agent (robot) and environment.
- Define notion of *static* and *dynamic* states.
- Provide examples of robot and environment states.

41.1. Preliminaries

Some/all of the following could be simplified or omitted and instead refer readers to reference material.

Discuss basics associated with

- Coordinate systems
- Reference frames
- Transformations

41.2. Robot Representations

Define the notion of:

- *pose* for mobile robots;
- *configuration* for manipulators
- robot and joint velocities

Discuss specific robot state representation for Duckietown.

41.3. 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 42**Software architectures and middlewares**

| Assigned to: Andrea

CHAPTER 43

Modern signal processing



| Assigned to: Andrea

CHAPTER 44

Basic Kinematics



| Assigned to: Jacopo

CHAPTER 45

Basic Dynamics



| Assigned to: Jacopo

CHAPTER 46

Odometry Calibration



| Assigned to: Jacopo

CHAPTER 47

Computer vision basics



| Assigned to: Matt

CHAPTER 48

Illumination invariance



| Assigned to: Matt

CHAPTER 49

Line Detection

..

| Assigned to: Matt

CHAPTER 50

Feature extraction



| Assigned to: Matt

CHAPTER 51

Place recognition

..

| Assigned to: Matt

CHAPTER 52

Filtering 1



| Assigned to: Liam

CHAPTER 53

Filtering 2

..

| Assigned to: Liam

CHAPTER 54

Mission planning

..

| Assigned to: ETH

CHAPTER 55

Planning in discrete domains

..

| Assigned to: ETH

CHAPTER 56

Motion planning



| Assigned to: ETH

CHAPTER 57

RRT

..

| Assigned to: ETH

CHAPTER 58

Feedback control



| Assigned to: Jacopo

CHAPTER 59

PID Control

..

| Assigned to: Jacopo

CHAPTER 60

MPC Control



| Assigned to: Jacopo

CHAPTER 61

Object detection

..

| Assigned to: Nick and David

CHAPTER 62

Object classification



| Assigned to: Nick and David

CHAPTER 63

Object tracking

..

| Assigned to: Nick and David

CHAPTER 64

Reacting to obstacles



| Assigned to: Jacopo

CHAPTER 65

Semantic segmentation



| Assigned to: Nick and David

CHAPTER 66

Text recognition



| Assigned to: Nick

CHAPTER 67

SLAM - Problem formulation

..

| Assigned to: Liam

CHAPTER 68

SLAM - Broad categories



| Assigned to: Liam

CHAPTER 69

VINS

| Assigned to: Liam

..

CHAPTER 70

Advanced place recognition



| Assigned to: Liam

CHAPTER 71

Fleet level planning (placeholder)

..

| Assigned to: ETH

CHAPTER 72

Fleet level planning (placeholder)



| Assigned to: ETH

CHAPTER 73

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 Hoehener, 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](#)).

PART 7

Exercises



These are the exercises.

CHAPTER 74

ROS Exercises

Progression of ROS skills:

74.1. Parameters

- Reading parameters
- Dynamic modification of parameters

74.2. Running from a log

- Running from a log

74.3. Unit tests

- Unit tests
- Integration with ROS tests

74.4. Analytics

- Measure the latency and frequency of the node
- Measure the latency of another node

74.5. Visualization

- Making a plot displayed using topic
- Using ROS parameters

CHAPTER 75
Line detection

..

CHAPTER 76

Data processing

..

CHAPTER 77

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 78

Ubuntu packaging with APT

78.1. apt install

TODO: to write

78.2. apt update

TODO: to write

1) apt dist-upgrade

TODO: hold back packages

78.3. apt-key

TODO: to write

78.4. apt-mark

TODO: to write

78.5. add-apt-repository

TODO: to write

78.6. wajig

TODO: to write

78.7. dpigs

TODO: to write

CHAPTER 79

GNU/Linux general notions



| Assigned to: Andrea



79.1. Background reading

- UNIX
- Linux
- free software; open source software.

CHAPTER 80

Every day Linux

80.1. cd

TODO: to write

80.2. sudo

TODO: to write

80.3. ls

TODO: to write

80.4. cp

TODO: to write

80.5. mkdir

TODO: to write

80.6. touch

TODO: to write

80.7. reboot

TODO: to write

80.8. shutdown

TODO: to write

80.9. rm

TODO: to write

CHAPTER 81

Users

..

81.1. passwd

..

TODO: to write

CHAPTER 82

UNIX tools

82.1. cat

TODO: to write

82.2. tee

TODO: to write

82.3. truncate

TODO: to write

CHAPTER 83

Linux disks and files

83.1. fdisk

TODO: to write

83.2. mount

TODO: to write

83.3. umount

TODO: to write

83.4. losetup

TODO: to write

83.5. gparted

TODO: to write

83.6. dd

TODO: to write

83.7. sync

TODO: to write

83.8. df

TODO: to write

CHAPTER 84

Other administration commands

84.1. visudo

TODO: to write

84.2. update-alternatives

TODO: to write

84.3. udevadm

TODO: to write

84.4. systemctl

TODO: to write

CHAPTER 85

Make

85.1. make

TODO: to write

CHAPTER 86

Python-related tools

86.1. virtualenv

TODO: to write

86.2. pip

TODO: to write

CHAPTER 87

Raspberry-PI commands

87.1. raspi-config

TODO: to write

87.2. vcgencmd

TODO: to write

87.3. raspistill

TODO: to write

87.4. jstest

TODO: to write

87.5. swapon

TODO: to write

87.6. mkswap

TODO: to write

CHAPTER 88

Users and permissions

88.1. chmod

TODO: to write



88.2. groups

TODO: to write



88.3. adduser

TODO: to write



88.4. useradd

TODO: to write



CHAPTER 89

Downloading

89.1. curl

TODO: to write

89.2. wget

TODO: to write

89.3. sha256sum

TODO: to write

89.4. xz

TODO: to write

CHAPTER 90

Shells and environments

90.1. source

TODO: to write

90.2. which

TODO: to write

90.3. export

TODO: to write

CHAPTER 91

Other misc commands

91.1. pgrep

TODO: to write

91.2. npm

TODO: to write

91.3. nodejs

TODO: to write

91.4. ntpdate

TODO: to write

91.5. chsh

TODO: to write

91.6. echo

TODO: to write

91.7. sh

TODO: to write

91.8. fc-cache

TODO: to write

CHAPTER 92

Linux resources usage

92.1. Measuring CPU usage using htop

You can use `htop` to monitor CPU usage.

```
$ sudo apt install htop
```

TODO: to write

92.2. Measuring I/O usage using iotop

Install using:

```
$ sudo apt install iotop
```

TODO: to write

92.3. How fast is the SD card?

→ Section 93.1.

CHAPTER 93

SD Cards tools

93.1. 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.

93.2. 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`.

93.3. 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 imagename.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.

Your 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 94

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:

94.1. hostname



TODO: to write

94.2. Visualizing information about the network



1) ping: are you there?



TODO: to write

2) ifconfig



TODO: to write

\$ ifconfig

CHAPTER 95

Accessing computers using SSH



Assigned to: Andrea

95.1. Background reading



TODO: to write

- Encryption
- Public key authentication

95.2. 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

95.3. 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.

95.4. 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`.

95.5. 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.

```
Your identification has been saved in /home/username/.ssh/username@host.name
Your public key has been saved in /home/username/.ssh/username@host.name.pub
The key fingerprint is:
XX:XX:XX:XX:XX:XX:XX:XX:XX:XX:XX:XX:XX:XX:XX:XX:XX:XX:XX
The key's randomart image is:
+--[ RSA 2048]----+
|          .   |
|          o   .  |
|          o = o . o |
|          B . * o |
|          S o   0 |
|          o o   . E |
|          o o   o |
|          o +   |
|          ...  |
+-----+
```

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
...
```

95.6. 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 95.5.

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.

95.7. 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/*
```

95.8. ssh-keygen

TODO: to write

CHAPTER 96

Wireless networking in Linux

96.1. iwconfig

TODO: to write

96.2. 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 97

Moving files between computers

97.1. SCP

TODO: to write

- 1) Download a file with SCP
-

TODO: to write

97.2. RSync

TODO: to write

CHAPTER 98

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”).

98.1. External documentation

→ [A VIM tutorial.](#)

98.2. Installation

Install like this:

```
$ sudo apt install vim
```

98.3. vi

TODO: to write

98.4. Suggested configuration

Suggested `~/.vimrc`:

```
syntax on
set number
filetype plugin indent on
highlight Comment ctermfg=Gray
autocmd FileType python set complete isk+=.,(
```

98.5. Visual mode

TODO: to write

98.6. 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 99

Atom

TODO: to write

CHAPTER 100

Eclipse

TODO: to write

100.1. Installing LiClipse

TODO: to write

CHAPTER 101

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.)

101.1. Advantages of using Byobu

TODO: To write

101.2. Installation

On Ubuntu, install using:

```
$ sudo apt install byobu
```

101.3. Documentation

* See the screencast on the website <http://byobu.co/>.

101.4. Quick command reference

You can change the escape sequence from [**Ctrl**-](#) to something else by using the configuration tool that appears when you type [**F9**](#).

Commands to use windows:

TABLE 14. WINDOWS

	Using function keys	Using escape sequences
Create new window	F2	Ctrl-<a> then C
Previous window	F3	
Next window	F4	
Switch to window		Ctrl-<a> then a number
Close window	F6	
Rename window		Ctrl-<a> then R

Commands to use panes (windows split in two or more):

TABLE 15. COMMANDS FOR PANES

	Using function keys	Using escape sequences
Split horizontally	Shift-F2	Ctrl-<a> then I
Split vertically	Ctrl-F2	Ctrl-<a> then %
Switch focus among panes	Ctrl-↑↓↔	Ctrl-<a> then one of ↑↓↔
Break pane		Ctrl-<a> then I

Other commands:

TABLE 16. OTHER

Using function keys	Using escape sequences
Help	<code>Ctrl-A</code> then <code>?</code>
Detach	<code>Ctrl-A</code> then <code>D</code>

101.5. Commands on OS X

Scroll up and down using `fn option ↑` and `fn option ↓`.

Highlight using `alt`



CHAPTER 102

Source code control with Git

Assigned to: Andrea

102.1. Background reading

TODO: to write

- Git
- GitFlow

102.2. 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.

102.3. 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
```

102.4. Git tips

1) Shallow clone

You can clone without history with the command:

```
$ git clone --depth 1 repository URL
```

102.5. 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
```

102.6. git

TODO: to write

CHAPTER 103

Git LFS



This describes Git LFS.

103.1. Generic installation instructions



See instructions at:

<https://git-lfs.github.com/>

103.2. 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
```

103.3. 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 104

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.

104.1. 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 52](#)).

The screenshot shows the GitHub sign-up interface. It has three input fields: 'greta-p' in the first, 'greta-p@duckietown.com' in the second, and a masked password in the third. Below the fields is a note: 'Use at least one lowercase letter, one numeral, and seven characters.' A green 'Sign up for GitHub' button is at the bottom, with a small note below it: 'By clicking "Sign up for GitHub", you agree to our [terms of service](#) and [privacy policy](#). We will send you account related emails occasionally.'

Figure 52

Go to your inbox and verify the email.

104.2. 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.

104.3. 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 95.5](#).

Result:

- You can access Github using the key provided.

Go to settings ([Figure 53](#)).

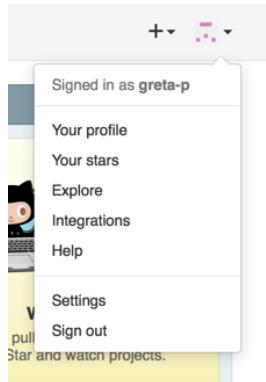


Figure 53

Add the public key that you created:



Figure 54

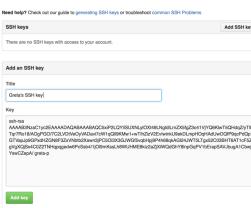


Figure 55



Figure 56

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 105

ROS installation and reference



Assigned to: Liam

105.1. 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
```

105.2. rqt_console



TODO: to write

105.3. roslaunch



TODO: to write

105.4. `rviz`

TODO: to write

105.5. `rostopic`

TODO: to write

1) `rostopic hz`

TODO: to write

2) `rostopic echo`

TODO: to write

105.6. `catkin_make`

TODO: to write

105.7. `rosrun`

TODO: to write

105.8. `rostest`

TODO: to write

105.9. `rospack`

TODO: to write

105.10. `rosparam`

TODO: to write

105.11. `rosdep`

TODO: to write

105.12. `rosrun`

TODO: to write



105.13. `rosbag`

```
$ rosbag reindex bag file
```



105.14. `roscore`

TODO: to write



105.15. 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 95.3](#).

105.16. 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 106

Python

106.1. Background reading

- Python
- Python tutorial

106.2. Python virtual environments

Install using:

```
$ sudo apt install virtualenv
```

106.3. Useful libraries

```
matplotlib  
seaborn  
numpy  
panda  
scipy  
opencv  
...
```

CHAPTER 107

Duckietown code conventions

107.1. Python

Never use tabs in the file.

✓ checked by what-the-duck.

Indentation is 4 spaces.

Lines should be below 90 characters.

All files have an encoding declared.

Executable files start with:

```
#!/usr/bin/env python
```

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
```

CHAPTER 108

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 153.1) 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.

108.1. Environment variables



You need to have set up the variables in Table 17.

TABLE 17. ENVIRONMENT VARIABLES USED BY THE SOFTWARE

variable	reasonable value	contains
<code>DUCKIETOWN_ROOT</code>	<code>~/duckietown</code>	Software repository
<code>DUCKIEFLEET_ROOT</code>	<code>~/duckiefleet</code>	A repository that contains <code>scuderia.yaml</code> and other team-specific configuration.
<code>DUCKIETOWN_DATA</code>	<code>~/duckietown-data</code>	Contains data for unit tests (Dropbox folder)

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.

108.2. 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 4.

```
emma:  
  username: andrea  
  owner_duckietown_id: censi
```

Listing 4. 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.

108.3. The machines file

The `machines` file is created using:

```
$ rosrun duckietown create-machines-file
```

108.4. 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.

CHAPTER 109

Node configuration mechanisms



TODO: Where the config files are, how they are used.

CHAPTER 110

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.

110.1. 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 *
```

110.2. 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 88.1](#).

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 `rosmsg 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.

110.3. 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][howto-launch-file] 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)
```

Every time the timer ticks, a message is generated and published.

3) Subscriber callback

Contents:

```
def cbTopic(self,msg):
    rospy.loginfo("[%s] %s" %(self.node_name,msg.data))
```

Every time a message is published to `~topic_b`, the `cbTopic` function is called. It simply prints the message using `rospy.loginfo`.

110.4. 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` specifies 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"` directs 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 from="~topic_b" to="talker/topic_a"/>` 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.

110.5. 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
```

110.6. 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.

110.7. 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 111

ROS package verification

This chapter describes formally what makes a conforming ROS package in the Duckietown software architecture.

111.1. Naming

- For exercises packages, the name of the package must be `package_handle`.

111.2. `package.xml`

- There is a `package.xml` file.
- Checked by `what-the-duck`.

111.3. Messages

- The messages are called

111.4. Readme file

- There is a `README.md` file
- Checked by `what-the-duck`.

111.5. Launch files

- there is the first launch file

111.6. Test files

`TODO: to write`

CHAPTER 112

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 113

Teleoperation



TODO: add video here



113.1. Implementation



Drivers:

- Chapter 154 - Package `adafruit_drivers`
- Chapter 164 - Package `pi_camera`

Operator interface:

- Chapter 159 - Package `joy_mapper`



113.2. Camera



TODO: to write



113.3. Actuators



TODO: to write



113.4. IMU

TODO: to write

CHAPTER 114

Parallel autonomy

..

TODO: to write

CHAPTER 115

Lane control



TODO: video here



115.1. Implementation

Perception:

- Chapter 155 - Package `anti_instagram`
- Chapter 158 - Package `ground_projection`
- Chapter 163 - Package `line_detector`, Chapter 162 - Package `line_detector2`
- Chapter 161 - Package `lane_filter`

Control:

- Chapter 160 - Package `lane_control`
- Chapter 156 - Package `car_supervisor`
- Chapter 157 - Package `dagu_car`

CHAPTER 116

Indefinite navigation

..

TODO: add video here

..

116.1. Implementation

The packages involved in this functionality are:

- [Chapter 165 - Package `apriltags_ros`](#)
- [Chapter 166 - Package `fsm`](#)
- [Chapter 167 - Package `indefinite_navigation`](#)
- [Chapter 168 - Package `intersection_control`](#)
- [Chapter 169 - Package `navigation`](#)

| **Note:** we don't discuss the details of the packages here; we just give pointers to them.

CHAPTER 117

Planning



TODO: add video here



117.1. Implementation



The packages involved in this functionality are:

- [Chapter 172 - Package localization](#)
- [Chapter 171 - Package duckietown_description](#)

| **Note:** we don't discuss the details of the packages here; we just give pointers to them.

CHAPTER 118

Coordination



TODO: add video here



118.1. Implementation

- Chapter 173 - Package led_detection
- Chapter 174 - Package led_emitter
- Chapter 175 - Package led_interpreter
- Chapter 176 - Package led_joy_mapper
- Chapter 178 - Package traffic_light
- Chapter 177 - Package rgb_led

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 C T 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 119

General remarks

Assigned to: Andrea

119.1. 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.

119.2. 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.

119.3. 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.

119.4. Accounts for all instructors and TAs

As an instructor/TA for the Fall 2017 class, in addition to the accounts above, these 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 120

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 121

Additional information for UdeM students



| Assigned to: Liam

TODO: to write

CHAPTER 122

Additional information for TTIC students



Assigned to: Matt

TODO: to write

CHAPTER 123

Additional information for NCTU students



Assigned to: Nick

TODO: to write

CHAPTER 124

Milestone: ROS node working



CHAPTER 125**Homework: Take and process a log**

CHAPTER 126

Milestone: Calibrated robot



CHAPTER 127**Homework: Camera geometry**

CHAPTER 128

Milestone: Illumination invariance

..

CHAPTER 129**Homework: Place recognition**

..

CHAPTER 130

Milestone: Lane following

..

CHAPTER 131**Homework: localization**

1

CHAPTER 132

Milestone: Navigation

..

CHAPTER 133

Homework: group forming

•

•

CHAPTER 134

Milestone: Ducks in a row

..

CHAPTER 135**Homework: Comparison of PID**

..

CHAPTER 136
Homework: RRT

..

CHAPTER 137
Caffe tutorial

..

CHAPTER 138

Milestone: Object Detection



CHAPTER 139
Homework: Object Detection



CHAPTER 140

Milestone: Semantic perception

..

CHAPTER 141

Homework: Semantic perception

• •

CHAPTER 142

Milestone: Reacting to obstacles

..

CHAPTER 143

Homework: Reacting to obstacles



CHAPTER 144
Milestone: SLAM demo



CHAPTER 145
Homework: SLAM

• •

CHAPTER 146

Milestone: fleet demo

..

CHAPTER 147
Homework: fleet

• •

CHAPTER 148

Project proposals

..

CHAPTER 149

Template of a project



149.1. Checklist for students



- Have a Github account. See [Chapter 104](#). 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).

149.2. Checklist for TAs



- Be signed up on

PART 12

Packages - Infrastructure

..

TODO: to write

CHAPTER 150

Package duckietown



TODO: to write

CHAPTER 151

Package duckietown_msgs

TODO: to write

CHAPTER 152

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.

152.1. 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.

152.2. 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

152.3. Automatic docs generation



Generate the docs for each node using this command:

```
$ rosrun easy_node generate_docs.py
```

CHAPTER 153

Package what_the_duck

`what-the-duck` is a program that tests *dozens* of configuration inconsistencies that can happen on a Duckiebot.

153.1. What the duck

To use it, first compile the repository, and then run:

```
$ ./what-the-duck
```

153.2. 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.

153.3. 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
```

153.4. 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 154

Package adafruit_drivers

TODO: to write

CHAPTER 155

Package `anti_instagram`



TODO: to write

155.1. 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
```

155.2. Unit tests needed external files



These are other unittest that require the logs in DUCKIETOWN_DATA:

```
$ rosrun anti_instagram annotations_test.py
```

155.3. 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 156

Package car_supervisor



TODO: to write

CHAPTER 157

Package dagu_car

..

TODO: to write

CHAPTER 158

Package ground_projection



TODO: to write

CHAPTER 159

Package joy_mapper

TODO: to write

159.1. Testing

To test run:

- 1) connect joystick
- 2) `roslaunch launch/joy_mapper_test.launch`
- 3) the robot should move when you push buttons

159.2. Dependencies

- `rospy`
- `sensor_msgs`: for the `Joy.msg`
- `duckietown_msgs`: for the `CarControl.msg`

159.3. 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 160

Package lane_control

TODO: to write

160.1. 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 θ .

Parameter `theta_thres`: float

Maximum desired θ .

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 161

Package lane_filter



Assigned to: Liam

TODO: to write

161.1. 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_θ`: float; default value: `0.0`

TODO: Missing description for entry “`mean_d_θ`”.

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 162

Package line_detector2



This is a re-implementation of the package `line_detector` using the new facilities provided by `easy_node`.



162.1. 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:

```
💻 $ roslaunch 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/vwznjke4xvnhi9o/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 57](#).

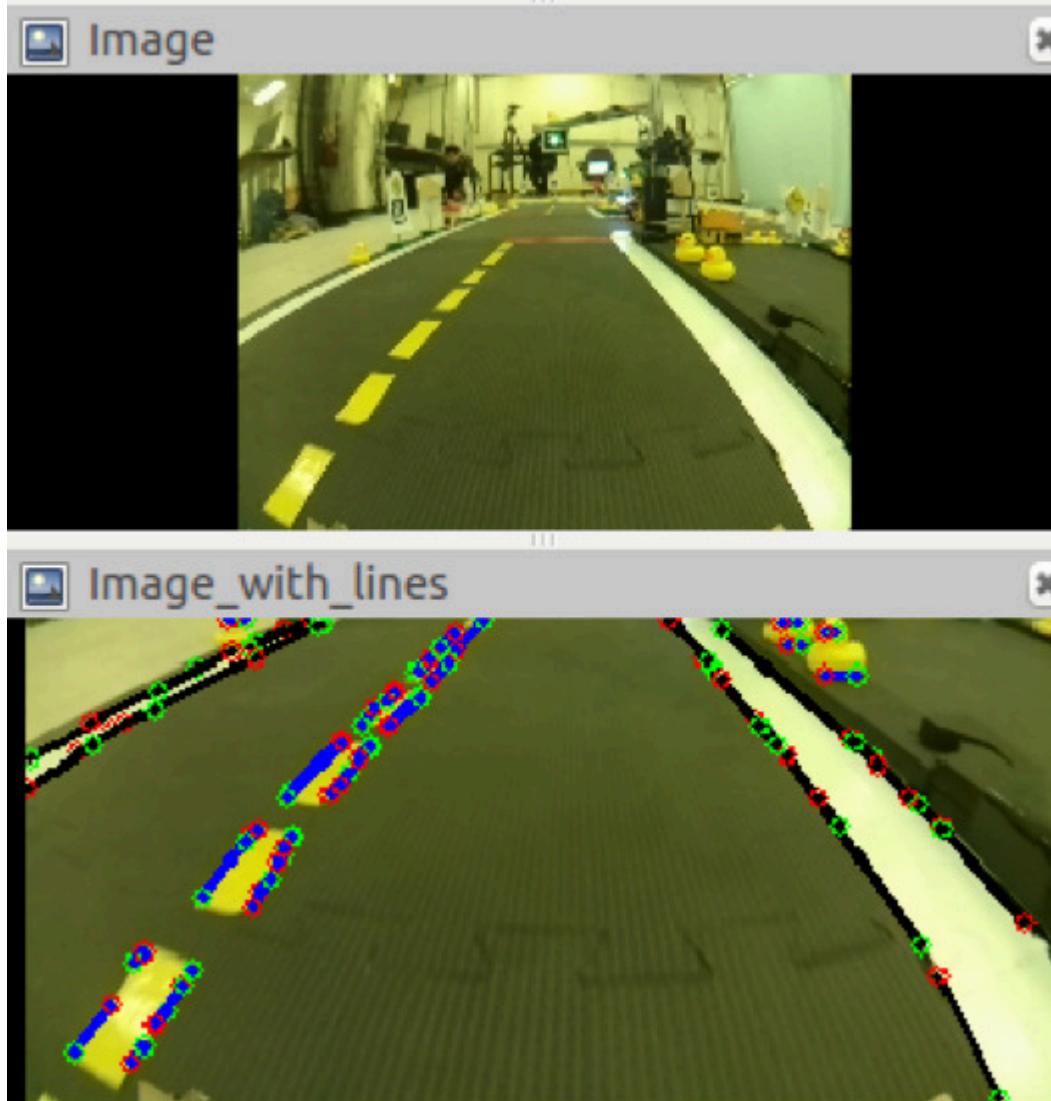


Figure 57

162.2. Quantitative tests

TODO: Something more quantitative (to be filled in by Liam or Hang)

162.3. 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 155](#).

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 163

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 164

Package `pi_camera`

TODO: to write

PART 14

Packages - Indefinite navigation

..

TODO: to write

CHAPTER 165

Package `apriltags_ros`

AprilTags for ROS.

build passing

CHAPTER 166

Package fsm

..

TODO: to write

CHAPTER 167

Package `indefinite_navigation`



TODO: to write

CHAPTER 168

Package intersection_control

..

TODO: to write

CHAPTER 169

Package navigation



TODO: to write

CHAPTER 170

Package stop_line_filter

TODO: to write

PART 15**Packages - Localization and planning**

TODO: to write

CHAPTER 171

Package duckietown_description

TODO: to write

CHAPTER 172

Package localization



TODO: to write

PART 16

Packages - Coordination

TODO: to write

CHAPTER 173

Package led_detection



TODO: to write

173.1. 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.

173.2. 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/5kx8qwgttu69fhr/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 174

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.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 175

Package led_interpreter

..

TODO: to write

CHAPTER 176

Package led_joy_mapper



TODO: to write

CHAPTER 177

Package `rgb_led`



TODO: to write

177.1. 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 178

Package traffic_light

TODO: to write

PART 17

Packages - Additional functionality

..

TODO: to write

PART 18

Packages - Templates



These are templates.

CHAPTER 179

Package `pkg_name`



The package `pkg_name` is a template for ROS packages.

For the tutorial, see [Chapter 110](#).



179.1. Status

Given an honest assessment of the status of this package.

CHAPTER 180

Package `rostest_example`

TODO: to write

PART 19

Packages - Convenience

TODO: to write



CHAPTER 181

Package `duckietown_demos`



TODO: to write

CHAPTER 182

Package duckietown_unit_test

..

TODO: to write

PART 20

Packages - To sort



We need to decide where these packages go.

CHAPTER 183

Package `adafruit_imu`

183.1. Testing

To test run:

TODO

183.2. Dependencies

- `rospy`
- `sensor_msgs`: for the `Joy.msg`
- `duckietown_msgs`: for the `CarControl.msg`

183.3. 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 184

Package `duckie_rr_bridge`

TODO: to write

CHAPTER 185

Package duckiebot_visualizer

TODO: to write

CHAPTER 186

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 187

Package bag_stamper

TODO: to write

CHAPTER 188

Package kinematics



TODO: to write

CHAPTER 189

Package `visual_odometry`

..

TODO: to write

CHAPTER 190

Package mdoap



TODO: to write

CHAPTER 191

Package parallel_autonomy

TODO: to write

CHAPTER 192

Package scene_segmentation



TODO: to write

CHAPTER 193

Package veh_coordinator

TODO: to write

CHAPTER 194

Package vehicle_detection



TODO: to write

CHAPTER 195

Package `visual_odometry_line`

..

TODO: to write

PART 21

Packages - Failed projects



These packages are abandoned failed projects.

CHAPTER 196

Package mouse_encoder

Use a mouse as encoder. Requires read permission to `/dev/input/mice`.

196.1. Publish Topic

- `mouse_encoder/tick: geometry_msg/Point` message with number of ticks in the x and y direction.

196.2. Parameters

- `~dev_path`: Default to `/dev/input/mice`. Point to the device path of the mouse.

196.3. 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 197

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

197.1. 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.

197.2. 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.

197.3. 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.

197.4. 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 198

Package slam

..

TODO: to write

CHAPTER 199

Package `street_name_detector`

TODO: to write

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