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Association Léonard de Vinci
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Internship Report : Research and Development at the DVIC

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Chapitre 1

Acknowledgements

When I first discovered the DVIC in late 2019, I felt that rush of adrenaline that you have when you find a long lost dream. Not as a passing impulse – in fact it has been 5 years that I have participated in hackerspaces and maker labs just to find a community that I could grow with.

I found a home. The students and the staff here are kindred souls, interested in similar spheres of technology, ambitious and just as amazed as me at the exciting times we live in. And this for months on end – for this reason I wish to thank those who welcomed me, whom I now work alongside. Madalina, Tic and Tac, Vincent, Yliess and Thibault, who weathered this uncertain period of history within the lab, and that I got to know through our many conversations. To Brice, who worked alongside me after the darknesses of the lockdown. To Yliess and Gregor, who assisted very nobly when small bugs eventually drove me crazy.

Last but not least, the trust that Clement Duhart has instilled in me is truly heartwarming. I cannot thank him enough for giving me such a full and unrequited access to the laboratory, to entrust me with expensive equipment, and to have offered such constant support through these difficult times. I wouldn't be anywhere else right now. And since I can remember, I have wanted to work in innovation and in a workspace that gave me the freedom to design my own systems. Thank you for making it happen.

This internship has been, in many ways, a dream come true. And now as I have built these dancing drones, perhaps others will see the magic.

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Chapitre 2

Summary

In the last few years, the DVIC has expanded into many fields of technology : virtual reality, IOT, cybersecurity, and most recently, into robotics. I was tasked with building the robotics cluster for further innovative projects in this innovation laboratory. In so doing, I held a research, design and development role. My overarching project was to develop a virtual-to-real interface for robotics, where I worked on three core components. The first is hardware as I chose a drone model and material resources for other students. The second is software, where I developed robot control techniques on a PC to program different usecases. Finally, I developed infrastructure as I smoothened the various virtual-to-real pipelines (external motion capture ; networking the robot, the motion capture and the simulator). As a result, I enabled a set of technologies for the laboratory and I have created a set of tutorials as well as a website, strategically organised for knowledge transmission.

Depuis quelques années, le DVIC a développé ses capacités dans plusieurs domaines de technologie : la réalité virtuelle, les objets connectés, la cybersécurité, et plus récemment en robotique. Ma tâche fut de construire le cluster de robotique pour accueillir d'autres projets innovatifs au sein de ce laboratoire d'innovation. Mon rôle était donc celui d'un chercheur, concepteur et développeur de technologies. Mon projet primordial était de développer une interface pour passer de robots réels dans des mondes virtuels. Pour ainsi faire, mes résultats sont regroupés sous trois sections. La première est matérielle : j'ai choisi un modèle de drone et des ressources matérielles pour les autres étudiants. La seconde est logicielle : j'ai développé des techniques de contrôle de robots par PC pour programmer des scénarios variés. Finalement, j'ai initié l'infrastructure qui interface le matériel et le logiciel (calibrations du système de localization externe, la mise en réseau du robot, de la motion capture et du simulateur). A travers ce processus, j'ai fait plusieurs expéditions technologiques pour le laboratoire, d'où j'ai créé une série de tutoriels ainsi qu'un site que j'ai organisé de façon stratégique pour la transmission de connaissances.

Chapitre 3

Introduction

The DVIC has been a place for building innovative projects, from minute electronics demoes to drawn out robotics projects, and everything in between. In the last few years, the DVIC has expanded into many fields of technology : virtual reality, IOT, cybersecurity, and most recently, into robotics.

This is a field in which I have some experience. I integrated ESILV Engineering school in January 2020, as a transfer from a different Masters in Drones at EFREI, a separate engineering school. While I was there, I led a team of students to enter a drone programming competition called Alpha Pilot. This was a raced designed solely for autonomous drones, that is, drones that fly themselves without human intervention.

Perhaps the best thing to come out of this was realising how little we knew about the field of robotics. Designing a robotic drone is one thing – and it requires a fundamental understanding of mechanics to keep it from getting damaged. But the robot's flight stack is also a complex venture, requiring careful prioritizing the drone's activities like looking around itself, making a map, planning its trajectory and even planning its motor activity. I have heard this field be affectionately termed "introspective robotics" by a RoboHub podcast of August 2020. I urge you to listen to it as it can offer a better explanation of the field than I ever will.

With this internship, I had the opportunity of laying the groundwork for such projects, in a structured and thought-out manner. As I am writing this report for a wider audience, I am trying to keep the information as a broad overview. You will not find long drawn out code, but I assure you that my work threads all sorts of code. Instead, I have chosen to lay out the work as a broad overview, and I hope you will enjoy perusing it as much as I enjoyed putting it together.

Chapitre 4

Company monograph

4.1 The ALDV structure

L'Association Leonard de Vinci (ALDV) is made up of 4 schools and academic departments as well as transversal administrative services. The ALDV is the top level structure occupying the Pôle Léonard de Vinci. The DVIC umbrella organisation is the more specific structure where I carried out my internship within the ALDV.

4.1.1 The DVIC structure

The De Vinci Innovation Center (DVIC) can be described as an umbrella organisation within the Pôle Léonard de Vinci. Placed at the intersection between the different schools (ESILV, IIM, EMLV), it is the structure that governs the innovation spaces, of which the Fablab, various laboratories and academic tracks. A renouveau of the DVIC is currently underway, as its founder and current director Clement Duhart has successfully supporting projects, collaborated with student societies and brought in attention from the wider public to the lab. As an alumnus of the MIT Media Lab, renouned hackerspace and innovation laboratory, Mr Duhart has replicated such clear values : Radical Learning, Anti-Disciplinarity and Collective Intelligence.

The DVIC is an educational structure and increasingly so, an innovation laboratory. Just like the De Vinci Research Center (DVRC), they develop a portfolio of activity throughout their year. This activity is initiated by student associations, but also by academic programs. The DVIC boasts of a new specialised formation for students interested in innovation. The formation, entitled Innovation, Research and Manufacturing (IRM), is set to begin at the start of September 2020. More information on the DVIC is available at https ://dvic.devinci.fr/.

The IRM program has become an integral part of the DVIC, as it offers the opportunity to form students while building projects that expand the sphere of activity of the laboratory. Students are set to learn academic work on topics from artificial intelligence to electronics as they are relevant to technological innovation. The second component of their formation, and lesser planned one, is the joint development of innovative projects. Students can learn to use a particular set of technological tools, by applying them in project form. In so doing, students benefit from the resources of the DVIC : workspaces, fabrication and manufacturing equipment, high-performance computing and so forth.

Chapitre 5

The mission

5.1 Mission description

My role was to research and develop a robotic structure for the laboratory. In as much as possible, the work should align with state-of-the-art robotics. More importantly, my work should be implementable by further innovative projects in the lab. In this way, my mission was to enable a swath of technologies and transmit this knowledge through a set of tutorials.

In more detail, the internship's criteria are as follows :

Développement d'un environnement pour la coordination virtuelle de l'essaim

- Prise en main de technologies de robotique en essaim.
- Développement d'une interface virtuelle pour visualisation de robots dans leur environnement
- Interface entre logiciels de robotique et monde virtuel

Développement d'un environnement de travail

- Construction d'un espace grillagé et muni de capteurs pour les expériences de vol
- Développement d'une stack logiciel pour la supervision et l'analyse de vol en réalité virtuelle

Fabrication de drones liés par réseau

- Développement d'un hardware standard pour la conception de drone
- Développement d'une stack logiciel standard pour la stabilité et calcul de trajectoire

Mise en place de démo et rédaction de tutoriel
- Mise en place d'une procédure de démonstration
- Rédaction d'une série de tutoriels de prise en main et d'expertise de conception de drones.

These 4 sections derive of a range of domains as vast as :
- robotics hardware,
- programming robot group behaviour,
- better calculations of the robots' trajectories and
- ensuring stable and responsive robot behaviour in these robots,
- while monitoring them in real-time.

More specifically, my mission was to enable a swath of technologies and transmit this knowledge through a set of tutorials. The actual content looks to things as vast as initiating the laboratory in areas as vast as robotics hardware, programming robot group behaviour, better calculations of the robots' trajectories and ensuring stable and responsive behaviour in these robots, while monitoring them in real-time. These are effectively the internship's criteria.

5.2 Mission plan

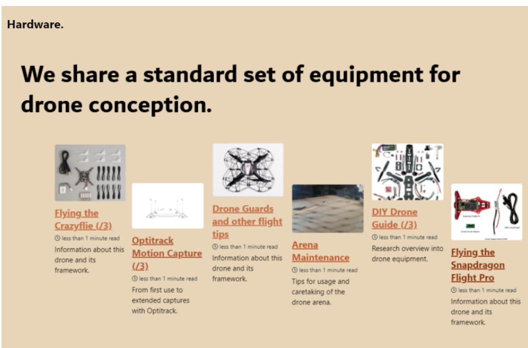
In order to choose the most efficient technologies and test them, I gradually build up a demo environment that I use to fly a drone. In this demo, I use and motivate a variety of technologies. The tutorials then split the work into three broad sections :
- Hardware : setting up robots and material resources for other students
- Software : control techniques on a PC to program different usecases
- Infrastructure : smoothening the various virtual-to-real pipelines (external motion capture; integration of simulators, etc.).

Finally, I organise the knowledge and techniques in a set of tutorials for students to get up to speed with sections relevant to their projects. Certain students in fact have a clarity about their projects, and I was able to address this in my tutorials by displaying how the technologies can be combined for different usecases.

A website will be created to this effect where knowledge transmission is enhanced by :
- Listing tutorials into the three sections (hardware, software, interface).
- Listing the tutorials by the technologies that are used.
- Cross-referencing the tutorials (e.g. how hardware relates to software).

(a) Software tutorials

(b) Hardware tutorials



(c) Infrastructure tutorials

The tutorials can be found on the website at https://autonomousdronedevelopers.github.io/.

Chapitre 6

Content

The three sections (software, hardware and infrastructure) were achieved through three projects. We explore each project in some detail, by describing the activities, the difficulties encountered and what solutions were taken. The sets of tutorials are our main source of results, other than the demoes of working projects.

6.1 Software

6.1.1 Requirements

This section consists of developing control techniques on a PC. This is a general field of work (robot motion involves control algorithms, state estimation, trajectory generation) and an overall approach needed to be taken. The priority at the time was to get a simple wheeled robots to move with very little prototyping, and thus to have a simulator that can test :

— coding bot behaviours based on what the bot observes,

— while also creating a modular environment for future students to use in the laboratory for their own prototyping.

6.1.2 Project definition

The first project is done purely in simulation, within the Gazebo simulator for robots. This project uses a wheeled bot in Gazebo and programs it to detect and approach a gate.

This project took a month because I needed to get up to speed with the technologies used (Gazebo, ROS, Python and OpenCV). Gazebo integrates a programmable middleware, ROS (Robot Operating System) that is convenient for waypoint following for robotics. This project is therefore clearly linked to autonomous drones, as they also can navigate by following waypoints.

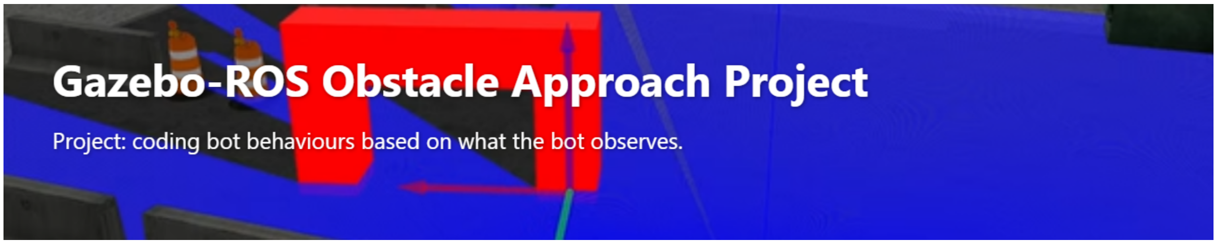


FIGURE 6.1: Project 1: Technical report available here.

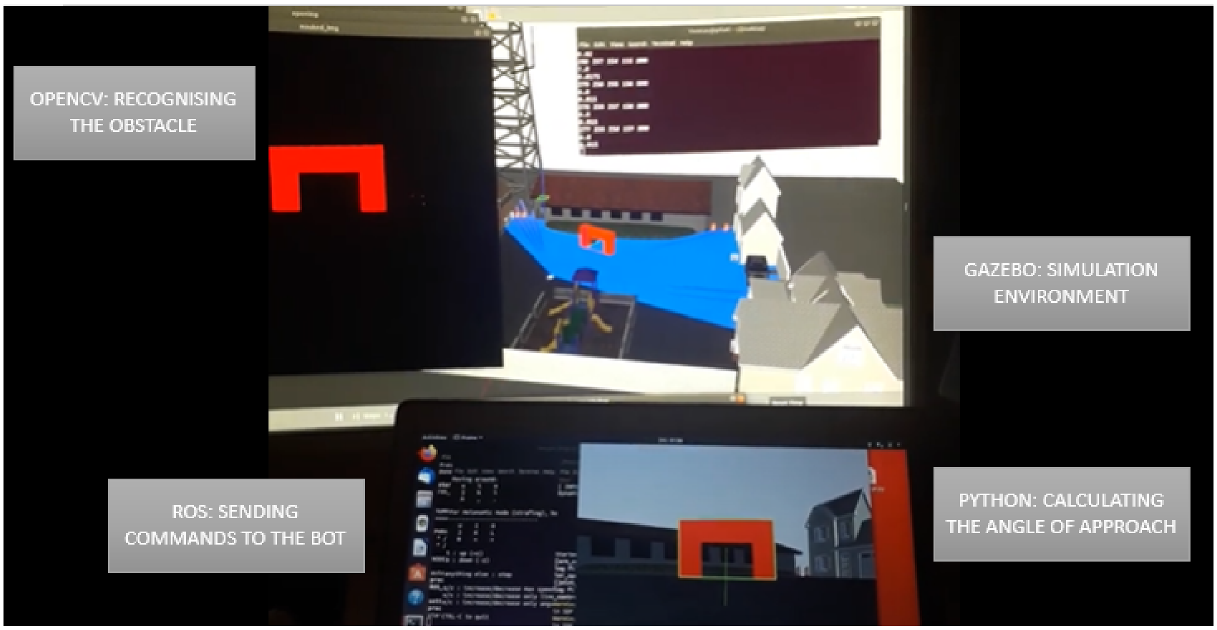


FIGURE 6.2: Technologies involved in Project 1.

Please consult the project page for more detailed technical work (Appendix A).

6.1.3 Difficulties and solutions

The biggest challenge in this project was to create a modular environment for future students to use. This meant setting up the 4 technologies seen above in such a way that they would function in coordination. However, since at the time (May 2020), these technologies were advancing at different rates, there were compatibility issues that were not resolved by the larger community. I solved this by developing a custom node that could combine Python 3, OpenCV 6 and ROS Melodic.

FIGURE 6.3: The list of software tutorials as of August 2020.

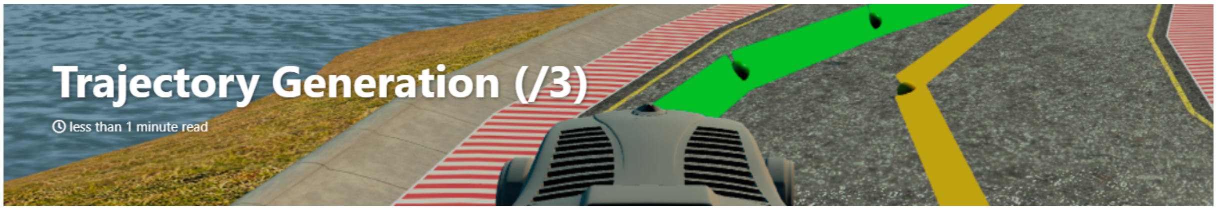


FIGURE 6.4: Link to the online tutorial
This tutorial is meant to cover the generation of trajectories for autonomous drone flight. Each usecase has different requirements, whether simply to reach a point, or to do so in a way that takes into account the environment and the constraints we put on the drone. The approach here will therefore start with demo-able results in constrained environments, and then form a more modular framework that allow more responsive, and more stable drone usecases.

FIGURE 6.5: Link to the online tutorial
This tutorial is meant to cover behaviour planning for robots in a variety of event-based scenarios.

6.1.4 Results

This project was completed and the final result is a demo video, accessible here. Finally, a series of tutorials has been derived from the project, each contributing to a specific element encountered during the project.The summary of each tutorial is available here and further information is available in the appendices.

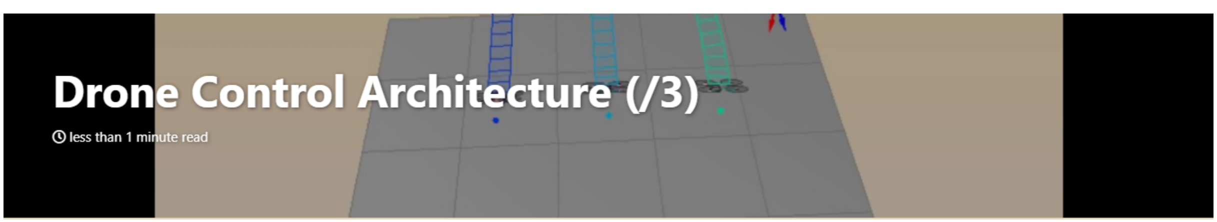


FIGURE 6.6: Link to the online tutorial
A foundational introduction to Control Theory, and its applications with drones.

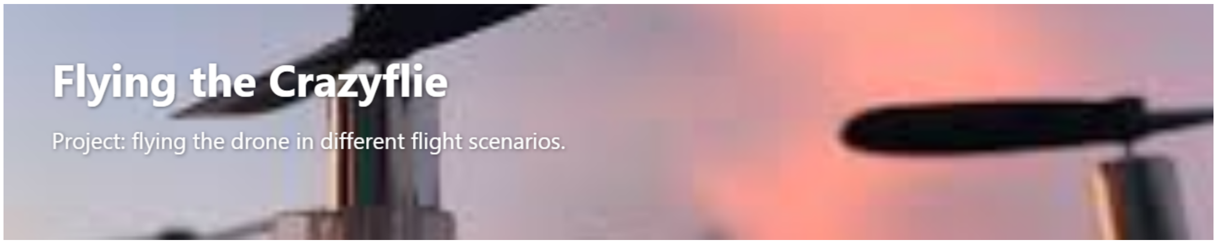


FIGURE 6.7: Link to the online tutorial

First, we get a Crazyflie drone up in the air using a list of waypoints. Most applications require this alone. The Crazyflie framework is a Python companion library that can perform automated behaviours, given a set of points. More intricate flight plans are developed with behaviour planning. The approach here will therefore start with demo-able results in constrained environments, and then form a more modular framework that allow more responsive, and more stable drone usecases.

6.2 Hardware

6.2.1 Requirements

This section consists of setting up robots and material resources for other students. The robots used in the laboratory widely between wheeled robots, aerial robots and other robotic devices. The priority at the time was to have a functional prototype of a dynamic robot, and if possible, one that can be used in a variety of scenarios for fast prototyping. Completing this section means operating onboard functionality successfully for the chosen robot, but also learning to maintain it. This functional prototype would therefore require :

- ROS compatibility
- Onboard trajectory planners
- An onboard control setup
- Preferably a small robot
- An easily maintained robot

6.2.2 Project definition

The project for this section carefully selects a drone specimen, and programs it to fly autonomously. We cover behaviour planning for a single drone using onboard hardware. The next project will later look to integrate this functionality into the drone swarm framework with multiple drones. As a result, the Crazyflie and the Crazyswarm projects were developed in parallel over a period of 2 months (June-July 2020).

FIGURE 6.8: The list of hardware tutorials as of August 2020.

6.2.3 Difficulties and solutions

Choosing the drone according to the requirements above was an arduous selection process. The drone that is chosen is the Bitcraze Crazyflie 2.1. The Crazyflie 2.1 is a self-assembled, open-hardware nano quadcopter that targets hobbyists and researchers. Its small size (92 mm diagonal rotor-to-rotor) and weight (27 g) make it ideal for indoor swarming applications. The firmware is open source and the flexibility of the platform makes it ideal for research, education or other applications where openness and full control is important. Its 6 to 7 minutes of flight time make it practical for testing autonomous flight algorithms, and it has become the drone of choice for research laboratories. It is particularly adept to autonomous control and coordination of multi-robot systems, since its small size allows for dense formations with low air turbulence. It also offers agility, as found in existing drone research in control optimisation for aggressive manoeuvres. More information on the Crazyflie can be found in the tutorial to this effect found in the results section.

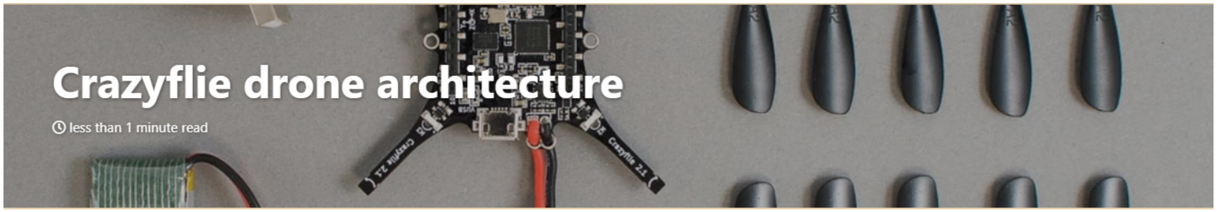


FIGURE 6.9: Link to the online tutorial
This tutorial is meant to cover the specific configuration of the Crazyflie 2.1 drone. In doing so, the firmware is explored to make the best use of this drone in the lab.

6.2.4 Results

This project was completed and the final result is a demo video, accessible here. Finally, a series of tutorials has been derived from the project, each contributing to a specific element encountered during the project.The summary of each tutorial is available here and further information is available in the appendices.

FIGURE 6.10: Link to the online tutorial

This project uses the Crazyflie drone specimen, and flies it within the Crazyswarm framework. This section covers drone setup and its flight within the arena designed to this effect.

6.3 Infrastructure

6.3.1 Requirements

This section consists of smoothening the various virtual-to-real pipelines in order to make a real robot achieve various functionality based on internal or external input. This tutorial is therefore directed at interaction designers who look to fly multiple drones using their own choice of inputs.

— First, a space needs to be made for drone flight. A drone arena needs to be developed that can house drones, but also accurately measure their movement.

— A framework needs to be identified that has all the necessary components for controlling multiple drones remotely, by relating the drone flight controller of the Crazyflie to a set of controllers on the PC, but also by offering ways to send trajectories to the drones in realtime. Ideally, this data interlinking would makes use of ROS which offers sufficient system modularity to use this framework in unprecedented, creative ways.

6.3.2 Project definition

This project is meant to cover the crazyswarm framework and how to use it to synchronise a drone's position with its expected position. Added to the above features, the main challenges in swarm robotics are addressed in this framework, namely the system latency in terms of system communication, and channel testing for the best signal possible.

A technology called Optitrack is to be adapted to my research in order to localize objects precisely without an internal localization mechanism. Motion capture is a discipline that consists of capturing elements in a 3D space and reconstructing the space virtually from such elements. My particular application uses position estimation for drone control.

FIGURE 6.11: The list of infrastructure tutorials as of August 2020.

6.3.3 Results

This project was partially completed and the current result is a demo video, accessible here. Finally, a series of tutorials has been derived from the project, each contributing to a specific element encountered during the project.The summary of each tutorial is available here and further information is available in the appendices.

FIGURE 6.12: Link to the online tutorial
Motion capture is a discipline that consists of capturing elements in a 3D space and reconstructing the space virtually from such elements. My particular application uses position estimation for drone control.

FIGURE 6.13: Link to the online tutorial
This tutorial is meant to cover the procedures used to take care of the Fablab drone arena.

6.4 The website

6.4.1 Requirements

A website is created for knowledge transmission and it is enhanced by :

- Listing tutorials into the three sections (hardware, software, interface).
- Listing the tutorials by the technologies that are used.
- Cross-referencing the tutorials (e.g. how hardware relates to software).

6.4.2 Results

The website is accessible at https ://autonomousdronedevelopers.github.io/

Hardware	7	Simulation	5
Robot	5	ROS	5
Planning	3	Simulator	3
Drone Arena	3	Motion Capture	2
Drone Specimen	2	Control	1
Vision	1	GPU	1
Drone swarming	1	Crossreality	1
Troubleshooting	1	Linux	1
Data Networking	1	Neat Demoes	1
Collaboration	1	Data manipulation	1
Jupyter	1		

FIGURE 6.14: The tutorials are categorised by technology used. This is useful for developers to peruse quickly.

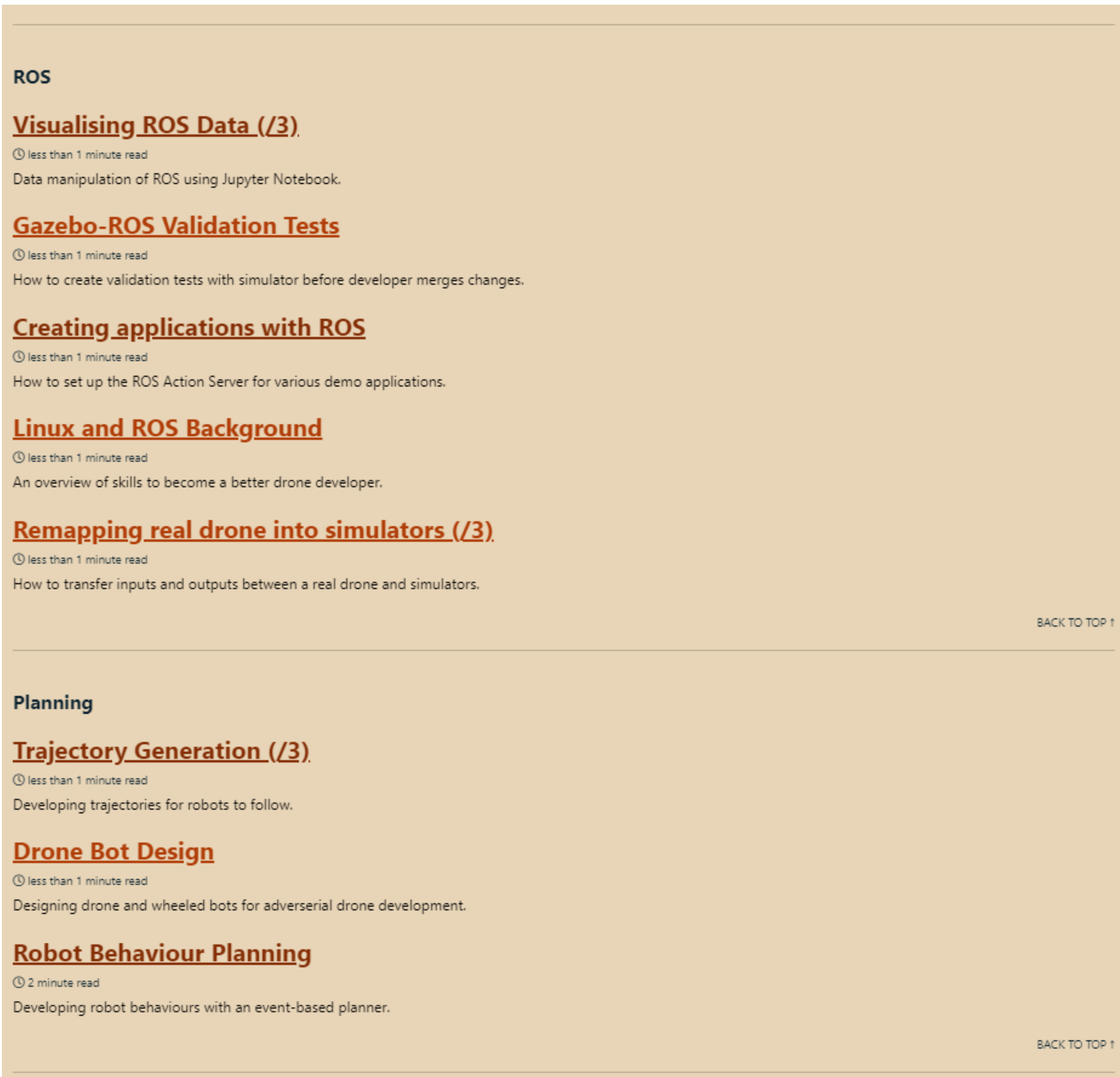
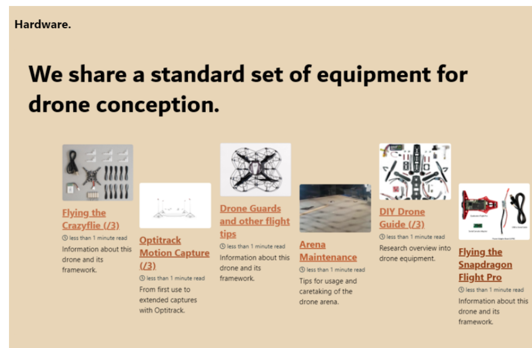
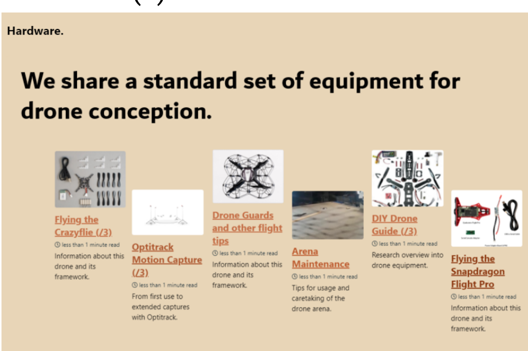


FIGURE 6.15: An example of the tutorials affected by different technologies.

(a) Software tutorials



(b) Hardware tutorials



(c) Infrastructure tutorials

FIGURE 6.16: Listing tutorials into the three sections (hardware, software, interface).

Chapitre 7

Conclusion

Throughout this internship, my mission was to enable a swath of technologies and transmit this knowledge through a set of tutorials. The actual content looks to things as vast as initiating the laboratory in areas as vast as robotics hardware, programming robot group behaviour, better calculations of the robots' trajectories and ensuring stable and responsive behaviour in these robots, while monitoring them in real-time. These are effectively the internship's criteria.

In order to choose the most efficient technologies and test them, I work on various projects that all contribute to a demo environment to fly a drone. In these projects, I use and motivate a variety of technologies, and the demo videos show project completion. The website's structure and the density of content that you can find on it are hopeful attempts at creating a space for knowledge transmission. As the new year comes, we will be able to tell if the website was, in fact, a success.

This project has been a labour of love. I invite you to explore the website in more detail, as it was impossible to incorporate all its elements without complicating the report somewhat. In remembering where I was a year ago, I wish I had resources like these sooner, back when we entered the autonomous drone race. I am looking forward to making that possible for others.