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Bibliography Report

Presented by

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**Making Flips With Quadrotors In Constrained
Environments**

Jury

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Abstract

Within the rapidly growing aerial robotics market, one of the most substantial challenges in the quadrotor community is performing aggressive maneuvers, especially multi-flip maneuvers. A proper physical definition of the issue is not addressed by the current approaches in the field and several key aspects of this maneuver are still overlooked. It can be shown, in particular, that making a flip with a quadrotor means crossing the parallel singularity of the dynamic model. The aim of the master thesis is to explore the possibility of defining aggressive trajectories for quadrotors on the basis of their dynamic model degeneracy analysis and to adapt various strategies to control the robot in a closed loop. In addition, the possibility to perform the aggressive maneuver in constrained environments will also be investigated. Therefore, the analysis will be extended from the previous studied to create general feasible trajectories that will allow quadrotors to perform aggressive flip maneuvers while passing through a constrained environment and while guaranteeing a satisfactory degree of robustness to the uncertainties of the dynamic model.

Acknowledgements

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Notations

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Introduction

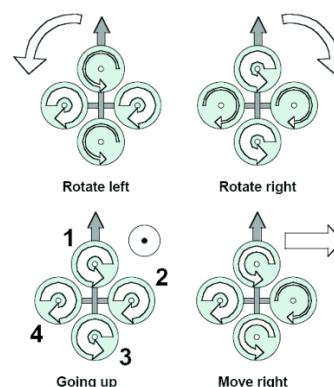
The aim of this section is to provide a general summary of the robotic platform that is used for this master thesis and to illustrate the main objective of the research work. In specific, in the sections below, quadrotors and parallel robots are briefly presented.

The quadrotor platform

A quadrotor is a type of unmanned aerial vehicle with four rotors and six degrees of freedom. Typically, drones have a small size and low inertia which allows it to be controlled by simple flight control systems. It is typically designed in a cross-configuration such that the electronics are held in the center of the platform and the rotors are placed at the borders. An example of a real quadrotor, namely the DJI Phantom, is shown in fig. 1a. The quadrotor is typically built in a way such that a pair of opposite rotors rotate clockwise, whereas the other pair of rotors rotates in counter-clockwise. The attitude and the position of the drone are controlled by changing the spinning speed of the rotors. An example is shown in figure 1b.



(a) A DJI Phantom quadcopter (UAV)



(b) Typical quadrotor configuration The width of the arrows is proportional to the angular speed of the propellers.[1]

Figure 1: A commercial quadrotor platform, with a typical quadrotor configuration.

The distinctive mechanical design of the quadrotor permits the actuation system to control all of the six degrees of freedom, even though it is under-actuated. This is due to the fact that the rotational and translational dynamics are tightly coupled. Thus, all the translational and rotational motions can be carried off by properly controlling the magnitude and direction of the spinning speed of the rotors.

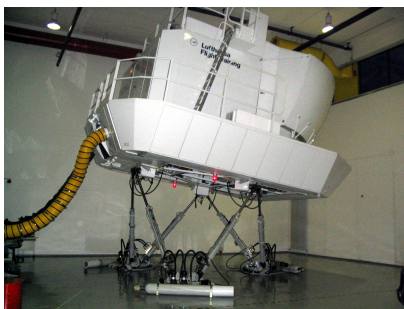
Over the last few years, quadrotors have gained a large popularity in academia and in the industry. This is due to several reasons, such as:

1. Quadrotors are very simple to design and they can be easily assembled using relatively cheap components.
2. As quadrotors became more and more affordable and dependable, the number of quadrotors real-world applications has grown significantly. They are being used for aerial photography, agriculture, surveillance, inspection tasks, in addition to many other uses as well.
3. Quadrotors are quite agile and maneuverable during flight. Especially when compared to other types of unmanned aerial vehicles (UAVs).

However, on the main challenges in the quadrotors community is the capability to design control and planning methods that will allow the quadrotors to carry out aggressive maneuvers. The fast dynamics associated with typically small dimensions of such agile quadrotors, in addition to several aerodynamic effects that will become important during aggressive flight maneuvers, are just a few of the main problems that are faced during the system control design. Moreover, accurate tracking of the provided trajectory is a very big issue in the case of aggressive maneuvers when the rotors are commanded high speeds and accelerations, which will cause rotors to become saturated and may also cause delays.

Parallel manipulators

A parallel manipulator is a mechanical system that consists of two connected platforms, the fixed platform and the moving platform. The latter is linked to the fixed platform thanks to at least two serial chains that are working in parallel. When compared to serial manipulators, parallel manipulators are more accurate and rigid. In addition, the ability to install the motors next to the fixed platform is a very important feature for parallel manipulators. Moreover, parallel manipulators can be used in a wide variety of applications that demand precision and high payload combined with high speed.[2]



(a) Gough-Stewart used for a flight-simulator application.¹



(b) The "PAR4" 4 degrees of freedom, high-speed, parallel robot prototype.²

Figure 2: Two examples of parallel robots.

¹https://en.wikipedia.org/wiki/Stewart_platform#/media/File:Simulator-flight-compartment.jpeg

²https://en.wikipedia.org/wiki/Parallel_manipulator#/media/File:Prototype_robot_parallel%20PAR4.jpg

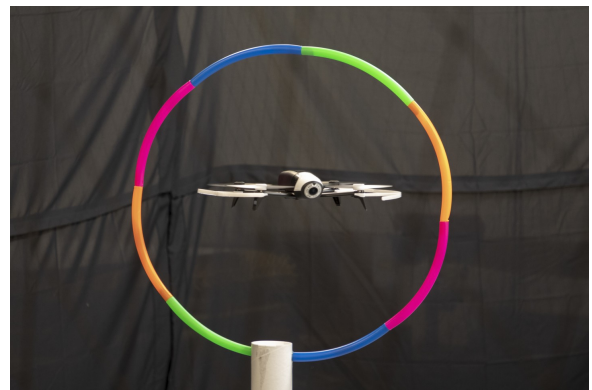
However, parallel manipulators are subject to singularities, which can lead to big problems in the robot workspace in case they were not handled correctly. Thus, the study of the singular configurations of parallel manipulators is very important. Because, even just before reaching a singularity, the performance of the parallel manipulator will decrease dramatically. Moreover, the robot may lose the ability of moving in a certain direction, gain uncontrollable motions and in the end the mechanism could even break. The main difference between serial and parallel manipulators is that singularity configurations may also appear inside the robot workspace (depending on the dimensions of the robot) and not just at the boundaries of the robot workspace, which can significantly decrease the area of the robot workspace. As a result, many works have been developed by robotics researchers in order to allow parallel manipulator manipulators to safely cross these singularities by using trajectory planning and specific control methods.

The goal of this thesis

This master thesis lies at the intersection of parallel robotics and aerial robotics. The two fields may seem very different from each other. However, quadrotors can be seen as a particular case of a parallel manipulator. In fact, a parallel manipulator is made up of a wrench system, applied by the robot limbs on the moving platform. And, this wrench system will define the motion of the moving platform. In the same manner, each propeller in a quadrotor can be considered as limb of a parallel robot and the moving platform to be controlled can be considered as the body of the drone. Specifically, the goal of this master thesis is to study a distinct class of aggressive maneuvers for quadrotors, namely multi-flip maneuvers. By doing multi-flip maneuvers, full rotations around one or more axes of the body of the quadrotor can be done. In addition, the quadrotor must also do the flips in a constrained environment.



(a) Quadrotor performing a triple flip.[3]



(b) Quadrotor going through a loop.¹

Figure 3: Representation of the issues to be tackled in this master thesis.

¹<https://newatlas.com/drones/muscle-signals-drone-control/#gallery:2>

Outline of the work





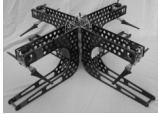
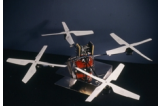




The rest of the bibliography is structured as follows:

- Chapter 1** is devoted to introduce the state of the art in quadrotor control in addition to introducing the dynamics of quadrotors. Specifically, a simplified dynamic model of the quadrotor will be presented by using Euler-Lagrange formalism. Then, moving on from the simple dynamic model, a more detailed dynamic model will be presented by using the Newton-Euler formalism. Finally, the state-space model of the quadrotor will also be derived.
- Chapter 2** provides an overview of the different potential control methods that can be used during the master thesis in order to properly control the quadrotor.
- Chapter 3** provides detailed explanations of how multi-flip maneuvers can be handled. Then, the link between a quadrotor performing a flip and a parallel robot crossing a singularity will be explained. In the end, a literature review is provided in order to show how the problem is tackled by different researches.
- Chapter 4** is devoted to trajectory optimization. By using trajectory optimization, it will be possible to create feasible trajectories for quadrotors to perform the aggressive maneuvers in constrained environments.

State of the art

The state of the art in the control of quadrotors has changed in a drastic way in the last few years. The number of projects tackling the problem of control of quadrotors has suddenly and significantly increased. Most of the projects are being done on commercially available quadrotor toys such as the Draganflyer

Table 1.1: Few quadrotor projects that have been done.[1]

Project	University	Picture
Mesicopter	Standord	
Thesis of E. Altug	Univ. Pennsylvania	
Thesis of P. Castillo	Univ. Compiègne	
Thesis of A. Clifton	Univ. Vanderbilt	
Thesis of P. pounds	ANU	
Thesis of N.Guenard	CEA	
Starmac	Stanford	
Thesis of M. Kemper	Univ. Oldenburg	
Thesis of P. Tournier	MIT	
MD4-200®	microDrones GmbH	

1.1 Dynamic model

The goal of this chapter is to present the dynamic model of the quadrotor. The mathematical notation and the physics of the quadrotor platform are expressed using the Newton-Euler formalism. Then, the state-space model that will be coded on the controller of the quadrotor will be derived.

1.2 State-space model

Control of quadrotors

- 2.1 General control architecture
- 2.2 Model Predictive control
- 2.3 Lyapunov Stability Analysis
- 2.4 Sliding mode control
- 2.5 Other types of control

Multi-flips maneuver with quadrotors

3.0.1 Quadrotor flip physics

3.0.2 Link to parallel robots

3.0.3 Control approaches for multi-flip maneuvers

Trajectory optimization

Conclusion

Bibliography

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- [3] S. Lupashin and R. D’Andrea, *Adaptive fast open-loop maneuvers for quadrocopters*. Manhattan, NY: Springer, 2012.