Preface

The opportunities to apply control principles and methods to mini-aircraft are flourishing in the beginning of the 21st century. Nonlinear modelling and modern nonlinear control theory play an important role in achieving high performance autonomous flight for new mini- and micro-flying machines. The rapid development is also due to the advances in computation, communication and sensing which are becoming increasingly inexpensive and omnipresent. This will make possible the development of new small UAVs (Unmanned Autonomous Vehicles) with sophisticated aerodynamical configurations. The use of automatic control theory will permit mini-aircraft to be more efficient and cost effective with a degree of intelligence and reactivity that will dramatically expand their field of applications.

This book presents a systematic study of modelling and nonlinear control of aerial vehicles taking into account mini-aircraft physical nonlinearities and aerodynamical forces, sensors and actuators limitations, and the effects of delays due to the computation time. The objective is to obtain control laws which perform satisfactorily even in presence of disturbances commonly encountered in real applications. This book presents also the development of platforms of aerial vehicles and an overview of the main sensors currently used in mini-UAVs.

This book particularly focus on aerial vehicles capable of hovering as helicopters as well as performing forward flight as normal planes. We study the following flying machines:

- A planar vertical take-off and landing vehicle (PVTOL aircraft).
- A four-rotor rotorcraft.[1]
- A reduced model of a classical helicopter.
- A mini-airplane (T-Wing).
- A mini-blimp.

[1] Also named quad-rotor rotorcraft.

Chapter 1 presents a brief history of aeronautics and particularly focuses on the evolution of multi-rotor rotorcraft. The success of aerial vehicles today would certainly not be possible without the relentless attempts realized in the last century by many courageous pioneers of the aerospace domain.

The model of the planar vertical take-off and landing aircraft represents a simplification of the model of a real vertical take-off aircraft. It also represents the longitudinal model of a helicopter. The control community has shown great interest in the PVTOL problem because it is an interesting and challenging theoretical problem of nonlinear systems which is clearly motivated by an application. Designing appropriate nonlinear controllers based on the PVTOL model can be used to improve the performance and the stability margins of the closed-loop system for vertical take-off and landing aircraft.

Chapter 2 presents a nonlinear control strategy for stabilizing the PVTOL using the approach of nested saturations. We have developed an experimental platform for testing the control algorithms we have proposed.

The four-rotor rotorcraft can be viewed as a generalization of the PVTOL in three-dimensional space. It can also be viewed as an alternative to standard helicopters having no swashplate. Four-rotor rotorcraft have fewer mechanical parts than standard mini-helicopters. This results in reduced time spent in maintenance. Given that the blades turn in opposite directions, the gyroscopic phenomena due to the blades is less important in quad-rotor rotorcraft than it is for standard helicopters. As a consequence quad-rotor rotorcraft have larger manoeuvrability but this also means that they tend to be more unstable. In Chapter 3 we present a nonlinear control strategy for stabilizing the helicopter having four rotors. The proposed control law has been tested in real-time experiments.

We have also carried out experiments to test the robustness of the controller with respect to delays which appear in the computation of the control law as well as in the computation of the position and orientation of the aircraft. We have studied in particular the controller used for the yaw angular displacement. We have designed a controller based on the prediction of the state and tested it in real-time flight. It has been shown that the system response remained basically unaffected in spite of significant delay. Chapter 4 presents these results.

In Chapter 5 we present the nonlinear model for the classical helicopter obtained using the Euler–Lagrange technique and also using the Newton laws. We have used the model we have obtained for designing a nonlinear control law based on the backstepping technique.

The control of a helicopter in 3D is an experiment which involves certain risks for the persons performing the study as well as for the equipment. In order to minimize the risks of accident we have built a vertical flying stand that allows the helicopter to move freely vertically and also to turn around the vertical axis. Although the behaviour of the helicopter in such a platform is different to its behaviour in free flight, this platform allows to gain a lot of insight on the problem and to perform experiments with limited risks.

The model of the helicopter during free flight reduces to a simpler model when it operates in the vertical flying stand. The model of the helicopter in the platform can also be obtained directly by using the Euler–Lagrange approach. Chapter 6 presents the model of the helicopter mounted on the vertical flying stand and a control law to stabilize the helicopter altitude and the yaw angular displacement.

For many years researchers have devoted much effort to developing planes that can take-off and land vertically. Such aircraft would require very inexpensive airport facilities. Chapter 7 presents the "T-wing" aircraft which is a new tailsitter plane developed by H. Stone at the University of Sydney. The nonlinear model structure, the identification of the aircraft parameters and the control algorithm for the T-wing are presented. We are indebted to Dr. H. Stone for writing this chapter.

Lighter than air vehicles, or blimps, are suitable for a wide range of applications such as advertising, aerial photography and aerial inspection platforms. They play an important role in environmental and climatologic research which require the development of autonomous airships. Chapter 8 presents a model of a blimp and the application of modern control theory of underactuated nonlinear systems to stabilize the airship. We thank Dr. Y. Bestaoui for writing this chapter.

Sensors are an essential part of the closed-loop control system. Sensors used in UAVs are rapidly changing. New sensors are more precise, lighter and less expensive than ever before. Chapter 9 presents an overview of the sensors that are currently used in mini-aircraft.

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