Advances in Aerospace Guidance, Navigation and Control

Joël Bordeneuve-Guibé · Antoine Drouin
Clément Roos
Editors

# Advances in Aerospace Guidance, Navigation and Control

## Selected Papers of the Third CEAS Specialist Conference on Guidance, Navigation and Control Held in Toulouse, France, in April 2015

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# About the Book

For the 3rd CEAS Specialist Conference on Guidance, Navigation and Control, the International Program Committee conducted a formal review process. Each paper was reviewed in compliance with good journal practice by at least two independent and anonymous reviewers. The papers published in this book were selected based on the results and recommendations from the reviewers.

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# Preface

The two first CEAS (Council of European Aerospace Societies) Specialist Conferences on Guidance, Navigation and Control (CEAS EuroGNC) were held in Munich, Germany in 2011 and in Delft, The Netherlands in 2013. ONERA The French Aerospace Lab, ISAE (Institut Supérieur de l'Aéronautique et de l'Espace) and ENAC (Ecole Nationale de l'Aviation Civile) accepted the challenge of jointly organizing the 3rd edition. The conference, chaired by Daniel Alazard and Felix Mora-Camino, took place on April 13–15, 2015, at ISAE-SUPAERO, Toulouse, France, one of the leading aerospace engineering schools in Europe. The Organizing Committee composed of Christelle Cumer and Nadine Barriety, and the International Program Committee composed of about 50 eminent scientists and engineers, strongly contributed to the success of this event. About a hundred papers were selected for presentation at the conference and this book contains the forty best contributions. The topics addressed here represent the most actively researched areas in guidance, navigation and control.

It is well known that the challenges are often more demanding in aerospace than in many other fields. The control of aerospace vehicles remains a difficult task because of ever larger flight domains, more complex and coupled dynamics, and wider variety of flying vehicles. Among the most promising control techniques, adaptive control has gained significant interest due to recent developments ensuring fast adaptation to environmental changes while preserving robust stability. A renewed interest in robust control is also observed. Recent advances in non-smooth optimization and developments of efficient softwares have contributed to bridge the gap between theory and practice, allowing these techniques to be used in many industrial applications. It is now possible for example to design very simple controllers such as PIDs using $H_\infty$ based techniques.

Visual servoing, also known as vision-based control, has emerged more recently with the development of small, accurate and affordable cameras. This technique uses feedback information extracted from vision sensors to control the motion of a vehicle or a robot. The ever-growing computer power makes it now possible to process the rich information provided by these sensors, which is an essential step towards the control and the guidance of vehicles with fast dynamics. Many theoretical and

practical results have already been presented, but solid mathematical analyses and proofs, real-time issues and efficient hardware implementations of image processing algorithms still deserve to be further investigated.

Then before flight testing, each aerospace vehicle has to go through a rigorous certification and qualification process to prove to the authorities that the flight control system is safe and reliable. Currently significant time and money is spent by the aeronautical industry on this task. Monte-Carlo simulations are used in most cases, but it is often difficult to isolate worst case scenarios or to confidently assert that no such scenario exists. Fortunately, many stability, performance, loads and comfort criteria can be reformulated as robustness analysis problems. Promising techniques such as multi-objective optimization under uncertainty using for example evolutionary algorithms can thus be applied to determine parameters/inputs/flight conditions for which the criteria are violated or poorly satisfied. A considerable effort is currently underway to enhance these techniques, motivated by the increase in computer power and the advent of multi-core processors, which allow to perform parallel computing at a reasonable cost.

These topics are all the more important that they are significant to both traditional aerospace vehicles as well as to emerging ones such as small Unmanned Aerial Vehicles (UAVs). Originating in the 60's as a military tool, UAVs have evolved from expensive and complicated military tools into inexpensive, relatively easy to use machines that are accessible to most people. Revenues generated by the activity have seen a tremendous growth as underlined by the initial public offering (IPO) of the DJI company.

This class of vehicles introduces many new challenges in term of control and navigation. Compared to classical flying vehicles, they perform a wider variety of missions, many of which including tightly space-constrained evolutions requiring high dynamics trajectories. Another particularity of those vehicles is that they are often operated closer to one another as well as to obstacles, requiring accurate and reactive navigation. As many of the applications intended for UAVs are motivated by their affordability, the costly validation and certification techniques traditionally used in aerospace can not be directly transposed. Their small mass and velocity imply limited consequences in case of crash and could justify relaxed regulations.

An additional advantage of this relaxed certification is the possibility of using the latest generation of microprocessors. The vast processing power available allows to experiment with a new class of algorithms that were previously inapplicable on other vehicles. The cost constraint limits the quality of sensors used on those vehicles and motivates new challenges for navigation algorithms, as does the use of innovative sensors like vision. Last but not least about unmanned systems, integration with Air Traffic Management has become a key issue that needs to be urgently tackled.

More recently, the same trend can be seen with CubeSats. Those small low cost satellites promise to offer a whole new range of applications once the technical and regulatory issues differentiating them from their full sized counterparts are be solved.

Obviously the papers presented at the conference and selected in this book do not suffice to fully cover all these challenging fields. However they represent an

excellent source of information for those seeking the latest theoretical and practical developments in guidance, navigation and control of aerospace vehicles.

The organization of the CEAS EuroGNC 2015 would have been impossible without the strong support of many people and communities. On behalf of the Local Organization Committee of CEAS EuroGNC 2015, we would like to thank all contributors to the conference. These contributors are: Council of European Aerospace Societies (CEAS), ONERA The French Aerospace Lab, ISAE, ENAC, American Institute of Aeronautics and Astronautics (AIAA), Fondation ISAE-SUPAERO, all members of the CEAS EuroGNC 2015 International Program Committee and all reviewers of technical papers.

The book is divided into four chapters : Guidance and Control, Navigation and Estimation, Atmospheric Applications and Space Applications. We hope you will enjoy reading this overview as much we enjoyed assembling it.

Toulouse, France
April, 2015

Joël Bordeneuve-Guibé
Antoine Drouin
Clément Roos

# Editorial Committee

# Biographies

Dr. Clément Roos graduated from ISAE-Supaéro (The French Superior Institute of Aeronautics and Space) in 2004. He holds a PhD in Automatic Control from ISAE-Supaero, for which he received two awards. He joined ONERA (The French Aerospace Lab) as a research scientist in 2007. He often takes part in industrial projects with Airbus and Dassault, and was notably involved in the European projects GARTEUR-AG17 and COFCLUO. His research interests focus on aircraft modeling, robustness analysis and control laws validation, as well as nonlinear design based on robustified dynamic inversion schemes and anti-windup synthesis. He is the author or co-author of several papers, book chapters, teaching documents and Matlab toolboxes. He also gives courses on automatic control, signal processing and flight mechanics at ISAE-Supaéro.

Dr. Antoine Drouin obtained his MSc degree in 1997 from ENAC (French Civil Aviation University) in Aerospace Engineering. He received his PhD in 2012 from the university Toulouse Paul Sabatier. The topic of his PhD research was the development of adaptive guidance laws for micro UAVs. For 6 years, Dr. Drouin worked for the French air navigation service provider as a software engineer specializing in high availability software. He worked specifically on the redundancy system for radar and flight

plan applications. From 2003 to 2006 he worked for the French air traffic control research center on the development of new generation graphical user interface and simulation code. Since 2007, Dr. Drouin has been a member of the faculty at ENAC, in the automatic control laboratory as assistant professor. Since 2003, he has been instrumental in the development of Paparazzi, an open source UAV system. He is involved in collaborations with foreign universities including the Georgia Institute of Technology and companies such as Joby Aviation. In 2000, Dr. Drouin began teaching at ENAC, initially in the field of operating systems and computer programming, and later in dynamical systems in addition to numerical programming. His research interests include navigation and nonlinear control theory.

Dr. Joël Bordeneuve-Guibé received the PhD degree in Automatic Control in 1990 from the Paul Sabatier University of Toulouse. The topic of the PhD was the multivariable predictive and adaptive control of industrial thermal processes. From 1991 to 1992, Dr. Bordeneuve-Guibé worked as a Research Assistant at the Department of Automatic Control of the Polytechnic University of Valencia, Spain (UPV). Since September 1992, Dr. Bordeneuve-Guibé is a research fellow at the Department of Mathematics, Computer Science and Control Design, Institut Supérieur de l'Aéronautique et de l'Espace (ISAE-Supaéro), Toulouse. His research interests are in adaptive and robust control, predictive control, spacecraft control and guidance. Dr. Bordeneuve-Guibé is currently associate professor of Automatic Control at ISAE-Supaéro.

# Contents

## Part I: Guidance and Control

## Part IV: Space Applications