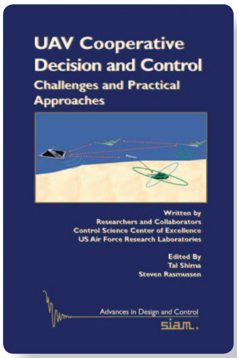
IEEE Control Systems Magazine welcomes suggestions for books to be reviewed in this column. Please contact either Michael Polis or Zongli Lin, associate editors for book reviews.



SIAM, 2008,
ISBN 0898716640,
186 pages, US$85.

UAV Cooperative Decision and Control: Challenges and Practical Approaches

by TAL SHIMA and STEVEN RASMUSSEN

Reviewed by Sonia Martínez

Broadly considered, the field of cooperative decision and control covers those interdisciplinary methods that can be used for operating of semi-autonomous agents deployed to achieve a common objective. By exploiting the agents' capabilities, it is expected that the combined effort of the team can exceed the sum of its parts. Harnessing this potential benefit, however, is challenging due to the complexity that dealing with miscellaneous components in dynamic and uncertain environments brings about.

In general, cooperative decision and control algorithms find application in the supervision of large networked systems, such as sensor and actuator monitoring networks, supply-chain management systems, the power grid, and traffic systems. A special and important use is the command and control of teams of unmanned aerial vehicles (UAVs) in surveillance and combat scenarios. This topic is the main focus of the book, which exposes research challenges and practical approaches for operating these systems in military scenarios.

More specifically, *UAV Cooperative Decision and Control: Challenges and Practical Approaches* describes several algorithms that enable a team of heterogenous UAVs to identify, classify, locate, and attack sets of targets under possibly imperfect information. These algorithms, a sample of the authors' work since the late 1990s, are analyzed according to aspects that include scalability, computational tractability, heterogenous vehicles, coordination under imperfect communications, and uncertainty due to false perception about the environment. As a valuable component, the book describes a simulation package, the MultiUAV2 Cooperative Control and Simulation tool. This simulation package is a Matlab/Simulink/C++ simulation tool, freely available to the public, which can be used to test any cooperative control algorithm under realistically modeled mission scenarios. For example, the user can test the algorithms against models of UAV dynamics, intervehicle communications, and various types of sensors.

As the authors point out, there are several types of cooperative controllers depending on the information available to agents, the organization of the agents, and the performance expected of the controllers. For example, controllers can be divided into centralized, hierarchical, or decentralized, respectively, depending on how global information is available to each, some, or none of the members of the team. The book focuses on centralized controllers since, at this point, these are the main class of controllers that can effectively handle general inter-vehicle and mission constraints. The methodology considered for centralized algorithm synthesis is based on different types of programming techniques and can deal with sources of uncertainty and false information.

Although primarily classifiable as a research monograph, the book does an excellent job in introducing the reader to the main issues of interest as well as a representative sample of cooperative control techniques employed in DoD scenarios. With respect to previous volumes [1]–[5], the text goes beyond the mere compilation of specialized papers, making an effort to present the subject in a unified way that is accessible to students, academicians, and nonspecialized control researchers alike. I personally believe the book achieves this objective, and parts of the book can be easily included into the syllabus of a graduate course on the subject. The book is one of the first in this area and complements recent publications such as [6]–[8], which pay more attention to decentralized controllers based on local interaction rules, such as those based on consensus algorithms, linear iterations, and geometric optimization problems.

ORGANIZATION AND CONTENTS

The book is organized into seven chapters and two appendices. Chapter 1 takes the reader through a historical tour on the development of UAVs and autonomous navigation systems. Team cooperation and its advantages in terms of joint efficiency and robustness to failure are introduced. A classification of cooperative controllers is made according to various metrics, such as the information available to UAVs (local versus global), the structure of the controller (centralized versus hierarchical versus decentralized), and its performance level (optimal or adaptive team behavior.) The chapter ends with

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a description of three example mission scenarios and the bottlenecks associated with them. These scenarios are combat intelligence, surveillance, and reconnaissance of moving ground targets; electronic attack to deceive a network of radars, that is, the *phantom problem;* and target classification in urban environments with micro air vehicles.

Chapter 2 expands on the discussion of the application of cooperative teams and challenges of cooperative control. The chapter starts by distinguishing among cooperative/noncooperative behaviors of multivehicle systems. Then, various distributed decision and control systems are revisited in terms of their performance capabilities. The discussion is followed by a description of the complexity spawned by cooperative controllers. Basically, the objective of reaching stringent performance requirements (task coupling, robustness, optimality, scalability) with limited controllers (partial local information, communication delays, high degree of autonomy) in uncertain environments is what leads to this complexity. As the authors note, there is no single approach that can address all the facets of cooperative control. Optimality can be addressed with mixed-integer linear programming and stochastic dynamic programming in centralized scenarios, but scalability is a limiting factor. On the other hand, decentralization can be in conflict with a severe team coupling imposed by the global performance index and objective constraints, which can lead to an excessive message traffic. Finally, communication limitations and false information raises the question of to what extent cooperation is beneficial. The rest of the book is devoted to describing approaches that the authors have found useful in the aforementioned scenarios. These approaches are multidisciplinary and bring together tools from fields such as operations research, computer science, and control theory.

Chapter 3 focuses on the problem of assigning UAVs to multiple targets. UAVs are small powered vehicles that have a life span of 30 min and can perform four tasks, search, classification, attack, and verification, in a specific order. Due to these capabilities, the tasks can be state constrained. For example, a constraint is imposed by the fact that an object classification can only be successfully performed under a certain UAV angle of attack. In this situation, the problem is solved through a linear programming formulation, as a *capacitated trans-shipment assignment problem* (CTAP). An iterative algorithm with memory weighting solves the N-target-N-UAV assignment problem in a fast way every time a new target is found, while respecting the task-precedence constraints. The algorithm is compared with Monte Carlo simulations, and the authors point out advantages and limitations of the CTAP approach.

Chapter 4 delves into the problem of multiple assignments for a group of UAVs through a mixed-integer linear programming approach. In contrast with the CTAP, this approach allows the inclusion of timing constraints and the consideration of a wider range of joint task assignment and scheduling problems. Alternatively, a decision tree formulation together with a breadth search algorithm and a genetic algorithm is explored to find globally optimal solutions. The chapter ends with simulations and a discussion on the pros and cons of all the algorithms introduced so far.

Chapter 5 considers the cooperative moving target engagement (CMTE) assignment problem. In this scenario, a group of heterogenous UAVs jointly track a moving ground target and intercept it. The various sensing capabilities of the UAVs (types of limited-sensing footprints, restrictions on relative bearing angles), timing constraints (a UAV can perform a tracking task only in some situations), and dynamical constraints (for example, one of the UAVs needs to fly in tight circular orbits) make this problem a highly complex one. An additional difficulty is the fact that the UAVs need to solve overlapping and joint tasks when planning for their paths. The authors translate this scenario into a combinatorial optimization problem by considering "time-availability windows," in which the UAVs are available to carry out a certain task. Then, the problem is reduced to how to combine the times that allow the completion of the task in minimum time. The paths of the UAVs are calculated to meet the time constraints. To solve this optimization problem, the authors explore the MILP and genetic algorithm approaches.

Chapter 6 discusses how imperfect communications and uncertainty may impact cooperative controllers and ways to overcome this. In connection with the assignment problems of previous chapters, the authors present a decision-estimation architecture that allows agents to use the CTAP approach from Chapter 3 in dealing with uncertainty in their teammates positions and their costs to intercept known targets. Here, uncertainty is a consequence of delays in the transmission of messages between agents or a possible asynchronous communication architecture.

An important source of uncertainty is due to the lack of information about the environment and targets. Chapter 7 explores this topic through effectiveness measurements. In particular, tools from probability and optimal control theory are used to find cooperative rules that maximize the probability of attacking at least n targets while constraining the probability of attaching m false targets. A numerical solution method is discussed and then evaluated in the situation of a single target scenario that is uniformly distributed in a linear-symmetric battle space among a Poisson field of false targets.

The book ends with two appendices. Appendix A presents the Multi-UAV2 simulation package, which models inter-vehicle communications, six-degree-of-freedom dynamics, and nonlinear aerodynamic lookup tables to accurately model the motion of the UAVs. The software can be used to model a variety of missions through the specification of "managers" to represent sensors, targets, weapons, and cooperation tactic rules.

Appendix B is on path-planning strategies for UAVs. The resulting algorithms could be part of a high-level module that would allow the UAVs to execute predefined flight paths. The appendix starts by discussing how track-guidance autopilots can be used to allow UAVs to follow a path. UAV modeling for path planning is discussed next through the Dubins kinematic-vehicle system. The appendix ends by discussing how to extend the available method for planning in the presence of wind.

CONCLUSIONS

UAV Cooperative Decision and Control: Challenges and Practical Approaches presents a unified approach to the management of multiple UAVs in military scenarios. The book describes precisely what the main challenges associated with the field are, which in turn motivate the high research activity in this area. By gradually increasing the level of complexity, it presents specific solutions to particular target assignment problems through a blend of methodologies, mainly from the field of optimization, making the exposition amenable to adaptation for a graduate course on the subject. As the authors note, many issues are left out of the scope of the book. For example, the inclusion of game-theoretic techniques for selfish agents would warrant a second volume. The contents can also be complemented with other books that deal with popular decentralized approaches, which are not covered here. Surely, this book is one of many to come in the area of cooperative decision and control, addressing numerous problems generated by this fascinating and high impact subject.

REVIEWER INFORMATION

Sonia Martínez is an assistant professor with the Mechanical and Aerospace Engineering Department at the University of California, San Diego. She received the Ph.D. in engineering mathematics from the Universidad Carlos III de Madrid, Spain, in May 2002. Following a year as a visiting assistant professor of applied mathematics at the Technical University of Catalonia, Spain, she obtained a postdoctoral Fulbright fellowship and held positions as a visiting researcher at the University of Illinois, Urbana-Champaign, and the University of California, Santa Barbara. Her main research interests include nonlinear control theory, robotics, cooperative control, and networked control systems. For her work on the control of underactuated mechanical systems, she received the Best Student Paper award at the 2002 IEEE Conference on Decision and Control. She was the recipient of an NSF CAREER Award in 2007. For the paper "Motion Coordination with Distributed Information," coauthored with Francesco Bullo and Jorge Cortes, she received the 2008 IEEE Control Systems Magazine Outstanding Paper Award.

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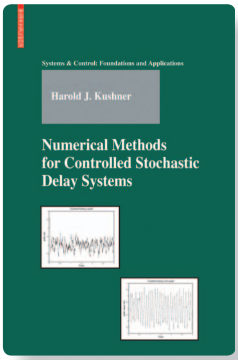
Book Announcements

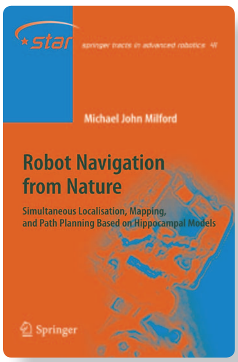


Birkhäuser, 2008, ISBN 978-0-8176-4534-2, 281 pages, US$69.95.

Numerical Methods for Controlled Stochastic Delay Systems

by HAROLD J. KUSHNER

This book extends Markov chain approximation methods used for the numerical solution of nonlinear continuous-time stochastic control problems to stochastic systems with delays. The system models covered includes diffusion and reflected diffusion processes, and the results can be extended to cover jump diffusions. This book is intended for researchers and graduate students interested in stochastic delay equations.

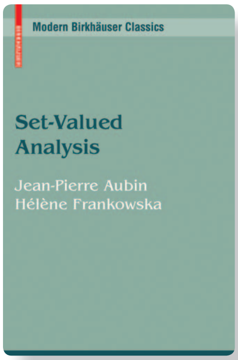


Springer, 2008, ISBN 978-3-540-77519-5, 196 pages, US$109.

Robot Navigation from Nature: Simultaneous Localisation, Mapping, and Path Planning Based on Hippocampal Models

by MICHAEL JOHN MILFORD

This book is written for researchers, graduate students, and professionals in robotics, especially robot navigation and computational neuroscience. The hippocampus has been studied extensively in rodents as part of the brain system responsible for navigation and spatial memory, and this book describes the development of a robot mapping and navigation system inspired by models of the neural mechanisms underlying spatial navigation in the rodent hippocampus.



Birkhäuser, 2009, ISBN 978-0-8176-4847-3, 461 pages, US$49.95.

Set-Valued Analysis

by JEAN-PIERRE AUBIN and HÉLÈNE FRANKOWSKA

This monograph in the Modern Birkhäuser Classics series is a reprint of the 1990 edition. The book gives an in-depth introduction and overview of the field. Since the applications to control are not specifically covered, the book is a basic resource for graduate students and researchers who are interested in the mathematics required to apply set-valued analysis in their work.

System Dynamics and Response

by S. GRAHAM KELLY

This undergraduate-level textbook provides a framework for understanding the modeling of dynamic systems and the determination of their response. The material is presented in four distinct parts: the mathematical modeling of dynamic systems, the mathematical solution of the differential and integrodifferential equations obtained

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