Preface

The use of unmanned aerial vehicles (UAVs) for various military missions has received growing attention in the last decade. Apart from the obvious advantage of not placing human life at risk, the lack of a human pilot enables significant weight savings and lower costs. UAVs also provide an opportunity for new operational paradigms. To realize these advantages, UAVs must have a high level of autonomy and preferably work cooperatively in groups. Exchanging information within these groups can greatly improve their capability.

In this context, a concentrated research effort has been conducted in recent years to develop novel cooperative decision and control algorithms. These algorithms deal with the problem of commanding multiple UAVs to cooperatively perform multiple tasks. The need is to assign specific tasks and flyable trajectories to each vehicle to maximize the group performance. The problem is challenging because the assignment task involves binary decision variables, while the path optimization involves continuous ones, and both are coupled. Also, to allow implementation, the developed algorithms must be solved in real time, possibly under uncertainty and communication constraints, and must be robust to failures.

This book provides an authoritative reference on U.S. Air Force relevant UAV cooperative decision and control problems and the means available to solve them. The book is aimed at helping practitioners, academicians, and students alike to better understand what cooperative decision and control is and its applications and methods for implementing algorithms that make cooperative UAV operations possible. The approach of this book is to present the UAV cooperative decision and control problem in a manner that abstracts the challenges from the concrete problems, making it possible to leverage the solution methods over a broader range of applications. To help researchers new to the field, and those already in the field, a thorough description of the problem and its challenges is presented. Solution algorithms that have recently been developed using various approaches will be presented, providing a baseline for further study.

To further enhance the subject matter, a multiple UAV simulation test bed, MultiUAV2, accompanies the text, making it possible for researchers to investigate new cooperative control strategies. MultiUAV2 is a Simulink–MATLAB–C++-based simulation that is capable of simulating multiple unmanned aerial vehicles that cooperate to accomplish predefined missions.

The outline of the book is as follows.

Chapter 1 gives an introduction to the cooperative decision and control problem. The road to autonomous control of UAVs is described and classes of cooperation are defined. Representative scenarios are used to describe and define the problem and its challenges.

Chapter 2 provides an in-depth study of the challenges associated with cooperative control of multiple UAVs. A taxonomy of teams is provided and the complexity of cooperative operation is analyzed. An overview of algorithms that could be used for cooperative control of UAV teams is presented.

Chapter 3 describes the baseline scenario of multiple UAVs performing multiple tasks on multiple targets. A linear programming formulation known as a capacitated transshipment assignment problem is then provided. This method is used to assign at each stage a single task to a single UAV. An iterative application of this algorithm, allowing the prosecution of multiple tasks on multiple targets, is then presented.

Chapter 4 presents three methods to assign multiple tasks to multiple UAVs in one step. These methods are mixed integer linear programming (MILP), tree search, and genetic algorithms (GA). Each has its respective pros and cons, which are described. Simulation results are also provided.

Chapter 5 studies a further complication of the cooperative problem, in which the multiple tasks on each target have to be performed simultaneously. This results in strict timing constraints for each task that must be addressed. The application of MILP and GA to this problem is studied and compared.

Chapter 6 deals with the cooperation of UAVs under communication delays. These delays may produce different information sets for the different UAVs in the group, leading to uncoordinated assignments. A decision-estimation architecture enhancing cooperation in such a scenario is presented. For the estimation process, communication and computation efficient algorithms are provided.

Chapter 7 presents effectiveness measures derived for UAV operations in uncertain environments. These measures provide a foundation for the rational evaluation of cooperation rules of engagement and for the effectiveness of aerial munitions, tactical UAVs, and general sensor craft.

Appendix A describes the MultiUAV2simulation and its operation.

Appendix B details the UAV path planning problem and Dubins' optimal trajectories.

All the material and experience contained in the book comes from research performed at the U.S. Air Force Research Laboratory's Control Science Center of Excellence within the Air Vehicles Directorate located at Wright-Patterson Air Force Base. The book is the result of almost a decade of research performed by in-house staff and contractors, collaborators from the Air Force Institute of Technology located at Wright-Patterson AFB, and visiting scientists.

As editors of this book, we would like to pay special gratitude to all the authors who contributed much time and effort to this endeavor. Special thanks go to Dr. Siva Banda, head of the Control Science Center of Excellence, for his vision and support of the research presented in this book. We also wish to extend our appreciation for the comments and suggestions of the reviewers, especially Prof. Anouck Girard, University of Michigan at Ann Arbor, who performed an extensive review on an early version of this manuscript. Last, we wish to thank Ms. Elizabeth Greenspan, the acquisitions editor of the Society for Industrial and Applied Mathematics, for her support and patience throughout the entire publication process.

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