DESIGNING MULTI-DRONE NETWORKS AND APPLICATIONS

by

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March 2017

A dissertation submitted to the
Faculty of the Graduate School of
the University at Buffalo, State University of New York
in partial fulfilment of the requirements for the
degree of

Doctor of Philosophy

Department of Electrical Engineering

Dedication

To my lovely wife, Zahra, and my wonderful parents, Parichehreh and Hossein, who have been selflessly helping me pursue my dreams.

Acknowledgments

I would like to express my deepest gratitude to Dr. Nicholas H. Mastronarde, my mentor, for his unlimited guidance, care, and support throughout my Ph.D. studies at the University at Buffalo. Dr. Mastronarde has not only shown me how to conduct groundbreaking research, but also how to be a productive member of the Academy.

I wish to thank Dr. Karthik Dantu for his insights on doing high-quality system's research, and my dissertation committee members Dr. Dimitris A. Pados, Dr. Weifeng Su, and Dr. Josep M. Jornet for their invaluable input and support.

My thanks also extend to Dr. Stella N. Batalama, Dr. Katharine Bartelo, Ms. Kimberly Kriz, Ms. Bin Chen, and Mr. Jason Tillman, for their generous care and encouragement during the hardest times of my Ph.D. journey.

I want to thank all my former and present colleagues, especially Prince Joseph, Dylan Elliott, Wei Shao, Alvin Alba, Jean Santiuste, and Farshad Ghanei. I feel extremely lucky to have worked with them during my Ph.D. studies. They made my life at UB more colorful and have enriched me with a lot of precious memories.

Last, but not least, I would like to thank my wife and my parents for their unconditional love and support.

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Abstract

Recent advances in rotorcraft design, multi-rotor vehicle control, miniaturization of hardware, sensing, and battery technologies have enabled cheap, practical design of micro air vehicles (MAVs) for civilian and hobby applications. In parallel, several applications are being envisioned that bring together networks of MAVs to accomplish large tasks by coordinating with each other. Despite these advancements, and new FAA rules governing their use, it is still very challenging to experiment with multiple networked MAVs. To mitigate these challenges, in this dissertation, we develop an open software/hardware platform called the University at Buffalo's Airborne Networking and Communications Testbed (UB-ANC). The UB-ANC ecosystem comprises three open-source projects: **UB-ANC Drone**, **UB-ANC Emulator**, and **UB-ANC Planner**. Our goal is to design, implement, and test MAV networking applications in simulation, and provide seamless transition to deployment.

UB-ANC Drone provides a flexible drone platform for robotics and network researchers to test and evaluate different mission planning algorithms and networking protocols on actual drones. **UB-ANC Emulator** provides a virtual environment for researchers to evaluate different algorithms in software and seamlessly transfer them to actual hardware (UB-ANC Drone). Finally, using these two platforms, we developed **UB-ANC Planner**, which is an energy-efficient

coverage path planner that aims to minimize the maximum energy consumption across drones as they search an arbitrary area with obstacles. In this dissertation, we describe all of these projects in detail.

Chapter 1

Introduction

1.1 Motivation

Micro air vehicles (MAVs[1]) are entering our daily life for a variety of applications including surveillance, search-and-rescue [1], emergency first response, package delivery, environmental monitoring, and precision agriculture. However, designing multi-drone networks and applications poses numerous interdisciplinary challenges because the underlying communications and networking problems cannot be explored independently from aero-mechanical, sensing, control, embedded systems, and robotics challenges [2, 3].

[1]We use the terms MAV, unmanned aerial vehicle (UAV), and drone interchangeably.

Chapter 2

UB-ANC Drone: A Flexible Airborne Networking and Communications Testbed

2.1 Introduction

Networked unmanned aerial vehicles (UAVs) have emerged as an important technology for public safety, commercial, and military applications including search and rescue, disaster relief, precision agriculture, environmental monitoring, and C3ISR (i.e., command and control, communications, intelligence, surveillance and reconnaissance). However, designing, implementing, and testing UAV networks poses numerous interdisciplinary challenges because the underlying communications and networking problems cannot be explored independently of aero-mechanical, sensing, control, embedded systems, and robotics challenges. Indeed, UAV networks are fundamentally *cyber-physical systems* [**?**].

Chapter 3

UB-ANC Emulator: An Emulation Framework for Multi-Agent Drone Networks

3.1 Introduction

Chapter 4

UB-ANC Planner: Energy Efficient Coverage Path Planning with Multiple Drones

4.1 Introduction

As noted previously, networked unmanned aerial vehicles (UAVs) have emerged as an important technology for public safety, commercial, and military applications including search and rescue, disaster relief, precision agriculture, environmental monitoring, and surveillance. Many of these applications require sophisticated mission planning algorithms to coordinate multiple drones to cover an area efficiently. Such scenarios are complicated by the existence of obstacles, such as buildings, requiring detailed planning for effective operation. Although a lot of work has been done on mission planning, optimal mission planning solutions depend heavily on the specific types of vehicles considered (e.g., ground robots, indoor drones, or outdoor drones), their kinematics, and the specific applications. Prior techniques have been optimized for shortest time to completion or control efficiency. However, a major challenge in the realization of such solutions is the limited energy on each drone.

Chapter 5

Conclusion

While there are many potential and emerging applications for multi-agent drone networks, deployment and testing of such systems is extremely challenging because it requires experience in networking, software systems, robotics, mission planning, and control among others. To mitigate these challenges, in this dissertation, we presented the University at Buffalo's Airborne Networking and Communications testbed (UB-ANC), which aims to facilitate the design of multi-drone networks and applications. UB-ANC comprises three components: the UB-ANC Drone, the UB-ANC Emulator, and the UB-ANC Planner. The UB-ANC Drone is a flexible open drone platform that provides tools for researchers to test and evaluate different mission planning algorithms and network protocols on actual drones. The UB-ANC Emulator aims to make it easy and convenient to design, implement, test, and debug distributed multi-agent mission planning algorithms in software to ensure correct system operation prior to experimentation in the field on actual UB-ANC drones. Finally, UB-ANC Planner is an energy-efficient coverage path planner, which aims to minimize the maximum energy consumption among drones covering an arbitrary area with obstacles. All projects are open source and available online at

https://github.com/jmodares.

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