

Autonomous Helicopter Formation using Model Predictive Control

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Formation flight is the primary movement technique for teams of helicopters. However, the potential for accidents is greatly increased when helicopter teams are required to fly in tight formations and under harsh conditions. The starting point for safe autonomous flight formations is to design a distributed control law attenuating external disturbances coming into a formation, so that each vehicle can safely maintain sufficient space between it and all other vehicles. In order to avoid the conservative nature inherent in distributed MPC algorithms, we begin by designing a stable MPC for individual vehicles, and then introducing carefully designed inter-agent coupling terms in each performance index. The proposed algorithm works in a decentralized manner, and is applied to the problem of helicopter formations comprised of heterogeneous vehicles. The disturbance attenuation property of the proposed MPC controller is validated throughout a series of computer simulations.

I. Introduction

ROTORCRAFT have revolutionized the offensive, defensive, reconnaissance, and security operations in the battlefield due to their mobility, range, and versatility (including vertical take-off and landing (VTOL) capability). With recent advances in technology, such as aerial refueling and night vision, helicopters have taken on increasingly important roles in military operations. Formation flight is the primary movement technique for helicopter teams.¹ By maintaining a coordinated formation, it is possible to achieve flight integrity with less fuel consumption than an unstructured flight, increasing the possibility of a mission's success.

Even with such unique flight capabilities, helicopter teams are confronted by very challenging situations. The potential for accidents is increased by requirements to fly in close formation and under harsh conditions including poor weather and extremely low altitudes. The effects of battlefield stress exerted on an aircrew increase dramatically under these adverse circumstances. We propose that computer-assisted autonomous formation flight procedures can be implemented to help to diminish battlefield stress.

Even though helicopter formation flight is of critical importance in various operations, little research has been done on this topic. Since helicopter dynamics are notoriously complex and uncertain, until recently it had not been feasible to design an automatic controller for a single helicopter. However, recent advances in system identification techniques and control of rotorcraft-based unmanned aerial vehicles (RUAVs)^{2,3} have provided insight into autonomous helicopter formation flight. Although several researchers have made efforts on the stable helicopter formation,⁴⁻⁵ their applications have been restricted to homogeneous formations in which all the vehicles have identical dynamics.

Model Predictive Control (MPC), also known as moving horizon or Receding Horizon Control (RHC), has been a useful technique for the control of slow dynamic systems such as chemical processes because the scheme requires high computational speed of the control hardware due to its on-line nature. Recently, the rapid development of digital processors, and powerful and inexpensive controllers make it possible to adopt MPC into hard real-time applications.⁶

MPC can provide a better performance in controlling uncertain plants since it can update the gain of the controller based on the current states, whereas fixed-gain control algorithms cannot.⁷ The capability to

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Table of Contents Autonomous Helicopter Formation Using Model Predictive Control

1. Understanding the eBook Autonomous Helicopter Formation Using Model Predictive Control
 - The Rise of Digital Reading Autonomous Helicopter Formation Using Model Predictive Control
 - Advantages of eBooks Over Traditional Books
2. Identifying Autonomous Helicopter Formation Using Model Predictive Control
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Autonomous Helicopter Formation Using Model Predictive Control
 - User-Friendly Interface

4. Exploring eBook Recommendations from Autonomous Helicopter Formation Using Model Predictive Control
 - Personalized Recommendations
 - Autonomous Helicopter Formation Using Model Predictive Control User Reviews and Ratings
 - Autonomous Helicopter Formation Using Model Predictive Control and Bestseller Lists
5. Accessing Autonomous Helicopter Formation Using Model Predictive Control Free and Paid eBooks
 - Autonomous Helicopter Formation Using Model Predictive Control Public Domain eBooks
 - Autonomous Helicopter Formation Using Model Predictive Control eBook Subscription Services
 - Autonomous Helicopter Formation Using Model Predictive Control Budget-Friendly Options
6. Navigating Autonomous Helicopter Formation Using Model Predictive Control eBook Formats
 - ePub, PDF, MOBI, and More
 - Autonomous Helicopter Formation Using Model Predictive Control Compatibility with Devices
 - Autonomous Helicopter Formation Using Model Predictive Control Enhanced eBook Features
7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Autonomous Helicopter Formation Using Model Predictive Control
 - Highlighting and Note-Taking Autonomous Helicopter Formation Using Model Predictive Control
 - Interactive Elements Autonomous Helicopter Formation Using Model Predictive Control
8. Staying Engaged with Autonomous Helicopter Formation Using Model Predictive Control
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Autonomous Helicopter Formation Using Model Predictive Control
9. Balancing eBooks and Physical Books Autonomous Helicopter Formation Using Model Predictive Control
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Autonomous Helicopter Formation Using Model Predictive Control
10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
11. Cultivating a Reading Routine Autonomous Helicopter Formation Using Model Predictive Control
 - Setting Reading Goals Autonomous Helicopter Formation Using Model Predictive Control
 - Carving Out Dedicated Reading Time

12. Sourcing Reliable Information of Autonomous Helicopter Formation Using Model Predictive Control
 - Fact-Checking eBook Content of Autonomous Helicopter Formation Using Model Predictive Control
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
 - Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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