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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 refuelling 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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Autonomous Helicopter Formation Using Model Predictive Control:

Autonomous Flying Robots Kenzo Nonami,Farid Kendoul,Satoshi Suzuki,Wei Wang,Daisuke Nakazawa,2010-09-15 The advance in robotics has boosted the application of autonomous vehicles to perform tedious and risky tasks or to be cost effective substitutes for their man counterparts Based on their working environment a rough classi cation of the autonomous vehicles would include unmanned aerial vehicles UAVs manned ground vehicles UGVs autonomous underwater vehicles AUVs and autonomous surface vehicles ASVs UAVs UGVs AUVs and ASVs are called UVs unmanned vehicles nowadays In recent decades the development of manned autonomous vehicles have been of great interest and different kinds of autonomous vehicles have been studied and developed all over the world In part ular UAVs have many applications in emergency situations humans often cannot come close to a dangerous natural disaster such as an earthquake a ood an active volcano or a nuclear disaster Since the development of the rst UAVs research efforts have been focused on military applications Recently however demand has arisen for UAVs such as aero robotsand ying robotsthat can be used in emergency situations and in industrial applications Among the wide variety of UAVs that have been developed small scale HUAVs helicopter based UAVs have the ability to take off and land vertically as well as the ability to cruise in ight but their most importantcapability is hovering Hoveringat a point enables us to make more eff tive observations of a target Furthermore small scale HUAVs offer the advantages of low cost and easy operation *Autonomous Formation Flight of Helicopters* Hoam Chung,2006 When a vehicle outside of the formation approaches a vehicle at the edge of the formation the motion of the vehicle at the formation edge acts like a disturbance with respect to the vehicle attempting to join the formation The vehicle at the edge of the formation cannot cooperate with any vehicle outside of the formation due to constraints on maintaining the existing formation Abstract shortened by UMI **Discrete Networked Dynamic Systems** Magdi S. Mahmoud,Yuanqing Xia,2020-10-22 Discrete Networked Dynamic Systems Analysis and Performance provides a high level treatment of a general class of linear discrete time dynamic systems interconnected over an information network exchanging relative state measurements or output measurements It presents a systematic analysis of the material and provides an account to the math development in a unified way The topics in this book are structured along four dimensions Agent Environment Interaction and Organization while keeping global system centered and local agent centered viewpoints The focus is on the wide sense consensus problem in discrete networked dynamic systems The authors rely heavily on algebraic graph theory and topology to derive their results It is known that graphs play an important role in the analysis of interactions between multiagent distributed systems Graph theoretic analysis provides insight into how topological interactions play a role in achieving coordination among agents Numerous types of graphs exist in the literature depending on the edge set of G A simple graph has no self loop or edges Complete graphs are simple graphs with an edge connecting any pair of vertices The vertex set in a bipartite graph can be partitioned into disjoint non empty vertex sets whereby there is an edge connecting

every vertex in one set to every vertex in the other set Random graphs have fixed vertex sets but the edge set exhibits stochastic behavior modeled by probability functions Much of the studies in coordination control are based on deterministic fixed graphs switching graphs and random graphs This book addresses advanced analytical tools for characterization control estimation and design of networked dynamic systems over fixed probabilistic and time varying graphs Provides coherent results on adopting a set theoretic framework for critically examining problems of the analysis performance and design of discrete distributed systems over graphs Deals with both homogeneous and heterogeneous systems to guarantee the generality of design results *Developments in Model-Based Optimization and Control* Sorin Olaru,Alexandra Grancharova,Fernando Lobo Pereira,2015-12-23 This book deals with optimization methods as tools for decision making and control in the presence of model uncertainty It is oriented to the use of these tools in engineering specifically in automatic control design with all its components analysis of dynamical systems identification problems and feedback control design Developments in Model Based Optimization and Control takes advantage of optimization based formulations for such classical feedback design objectives as stability performance and feasibility afforded by the established body of results and methodologies constituting optimal control theory It makes particular use of the popular formulation known as predictive control or receding horizon optimization The individual contributions in this volume are wide ranging in subject matter but coordinated within a five part structure covering material on complexity and structure in model predictive control MPC collaborative MPC distributed MPC optimization based analysis and design and applications to bioprocesses multivehicle systems or energy management The various contributions cover a subject spectrum including inverse optimality and more modern decentralized and cooperative formulations of receding horizon optimal control Readers will find fourteen chapters dedicated to optimization based tools for robustness analysis and decision making in relation to feedback mechanisms fault detection for example and three chapters putting forward applications where the model based optimization brings a novel perspective Developments in Model Based Optimization and Control is a selection of contributions expanded and updated from the Optimisation based Control and Estimation workshops held in November 2013 and November 2014 It forms a useful resource for academic researchers and graduate students interested in the state of the art in predictive control Control engineers working in model based optimization and control particularly in its bioprocess applications will also find this collection instructive **Advances in Swarm Intelligence, Part II** Ying Tan,Yuhui Shi,Yi Chai,Guoyin Wang,2011-05-26 The two volume set LNCS 6728 and 6729 constitutes the refereed proceedings of the International Conference on Swarm Intelligence ICSI 2011 held in Chongqing China in June 2011 The 143 revised full papers presented were carefully reviewed and selected from 298 submissions The papers are organized in topical sections on theoretical analysis of swarm intelligence algorithms particle swarm optimization applications of pso algorithms ant colony optimization algorithms bee colony algorithms novel swarm based optimization algorithms artificial immune system differential evolution neural networks

genetic algorithms evolutionary computation fuzzy methods and hybrid algorithms for part I Topics addressed in part II are such as multi objective optimization algorithms multi robot swarm robot and multi agent systems data mining methods machine learning methods feature selection algorithms pattern recognition methods intelligent control other optimization algorithms and applications data fusion and swarm intelligence as well as fish school search foundations and applications

Flight Formation Control Josep M. Guerrero,Rogelio Lozano,2012-12-17 In the last decade the development and control of Unmanned Aerial Vehicles UAVs has attracted a lot of interest Both researchers and companies have a growing interest in improving this type of vehicle given their many civilian and military applications This book presents the state of the art in the area of UAV Flight Formation The coordination and robust consensus approaches are presented in detail as well as formation flight control strategies which are validated in experimental platforms It aims at helping students and academics alike to better understand what coordination and flight formation control can make possible Several novel methods are presented controllability and observability of multi agent systems robust consensus flight formation control stability of formations over noisy networks which generate solutions of guaranteed performance for UAV Flight Formation Contents 1 Introduction J A Guerrero 2 Theoretical Preliminaries J A Guerrero 3 Multiagent Coordination Strategies J A Guerrero R Lozano M W Spong N Chopra 4 Robust Control Design for Multiagent Systems with Parametric Uncertainty J A Guerrero G Romero 5 On Adaptive and Robust Controlled Synchronization of Networked Robotic Systems on Strongly Connected Graphs Y C Liu N Chopra 6 Modeling and Control of Mini UAV G Flores Colunga J A Guerrero J Escare o R Lozano 7 Flight Formation Control Strategies for Mini UAVs J A Guerrero 8 Formation Based on Potential Functions L Garc a A Dzul 9 Quadrotor Vision Based Control J E Gomez Balderas J A Guerrero S SALAZAR R Lozano P Castillo 10 Toward Vision Based Coordination of Quadrotor Platoons L R Garc a Carrillo J A Guerrero R Lozano 11 Optimal Guidance for Rotorcraft Platoon Formation Flying in Wind Fields J A Guerrero Y Bestaoui R Lozano 12 Impact of Wireless Medium Access Protocol on the Quadrotor Formation Control J A Guerrero Y Challal P Castillo 13 MAC Protocol for Wireless Communications A Mendez M Panduro O Elizarraras D Covarrubias 14 Optimization of a Scannable Pattern for Bidimensional Antenna Arrays to Provide Maximum Performance A Reyna M A Panduro A Mendez **Robust Formation Control for Multiple Unmanned Aerial Vehicles** Hao Liu,Deyuan Liu,Yan Wan,Kimon Valavanis,Frank Lewis,2022-12-01 This book is based on the authors recent research results on formation control problems including time varying formation communication delays fault tolerant formation for multiple UAV systems with highly nonlinear and coupled parameter uncertainties and external disturbances Differentiating from existing works this book presents a robust optimal formation approach to designing distributed cooperative control laws for a group of UAVs based on the linear quadratic regulator control method and the robust compensation theory The proposed control method is composed of two parts the nominal part to achieve desired tracking performance and the robust compensation part to restrain the influence of highly nonlinear and strongly coupled parameter

uncertainties and external disturbances on the global closed loop control system Furthermore this book gives proof of their robust properties The influence of communication delays and actuator fault tolerance can be restrained by the proposed robust formation control protocol and the formation tracking errors can converge into a neighborhood of the origin bounded by a given constant in a finite time Moreover the book provides details about the practical application of the proposed method to design formation control systems for multiple quadrotors and tail sitters Additional features include a robust control method that is proposed to address the formation control problem for UAVs and theoretical and experimental research for the cooperative flight of the quadrotor UAV group and the tail sitter UAV group Robust Formation Control for Multiple Unmanned Aerial Vehicles is suitable for graduate students researchers and engineers in the system and control community especially those engaged in the areas of robust control UAV swarming and multi agent systems *Aerospace America* ,2006 □□□□□□□□□□□□□□□□—□□□□□□□□□□□□□□□□— □□□□,2020-08-12 2019 1 1 2 3 4 NEDO 5 Dissertation Abstracts International ,2009 **Journal of Guidance, Control, and Dynamics** ,2009 **International Aerospace Abstracts** ,1999 **Model Predictive Formation Control of Helicopter Systems** Medi Saffarian,2009 **Aeronautical Engineering: A Cumulative Index to a Continuing Bibliography (supplement 325)** ,1995 **NASA SP.** ,1992 **Aeronautical Engineering** ,1992 A selection of annotated references to unclassified reports and journal articles that were introduced into the NASA scientific and technical information system and announced in Scientific and technical aerospace reports STAR and International aerospace abstracts IAA Aeronautical Engineering: A Cumulative Index to a Continuing Bibliography (supplement 274) ,1992 **Model Predictive Control of an Unmanned Quadrotor Helicopter** Mahyar Abdolhosseini,2016 Model Predictive Control MPC has been well established and widely used in the process control industry since years However due to dependability of its success on availability of high computational power to handle burden of online repetitive calculations and existence of a precise mathematical model of the controlled plant it has found less application in other areas of systems and control specifically speaking when it comes to fast dynamics control systems featuring a highly elaborate plant Preceded by previous successful efforts made in the application of MPC to other areas of systems and control rather than process control this thesis initiates employment of MPC in the unmanned aerial systems industry To this end the system of the quadrotor UAV testbed in the Networked Autonomous Vehicles Laboratory of Concordia University is chosen A three dimensional autopilot control system within the framework of MPC is developed and tested through numerous flight experiments The overall performance of the quadrotor helicopter is evaluated under autonomous fight for three flight scenarios of trajectory tracking payload drop robustness to voltage current drop and fault tolerant control in the presence of faults induced by reduced actuator effectiveness This has been achieved by the proper use of a model reduction technique as well as a fast optimization algorithm to address the issues with high computation and incorporation of the integral action control in the MPC formulation to meet the offset free tracking requirement Both

simulation and experimental results are presented to demonstrate success of the design *Administration & Management* ,1983 **Mathematical Reviews** ,2004

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