A Reinforcement Learning Approach to Control of a Quadrotor Biplane Tailsitter for Adaptive Landing Maneuvers

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ABSTRACT

This paper presents a reinforcement learning (RL) based trajectory planning and control architecture for autonomous landing maneuvers of a quadrotor biplane tailsitter (QRBP). The RL controller replaces a gradient–descent based optimal trajectory planner and outer loop position controller of a standard QRBP control system, while retaining the inner loop for regulating attitude dynamics. The RL agents are trained in a simulated environment, using a curriculum learning approach for training an RL agent capable of landing on a moving Unmanned Ground Vehicle (UGV) with changing velocity. The RL architecture is capable of generating landing trajectories onto a moving ground vehicle, with computational costs suitable for real-time implementation. Further, the RL guidance architecture successfully completes the landing mission more consistently compared to a gradient–descent based guidance architecture when there is uncertainty in the path of the UGV.

INTRODUCTION

Unmanned Aerial Systems (UASs) are seeing a growing interest as a technology that can overcome delivery, mobility, and sensing challenges for a variety of applications (Refs. 1, 2). While the majority of research and application has been focused on pure fixed wing or vertical take–off and landing (VTOL) platforms, an emerging research area involves transitioning, or hybrid UASs. These hybrid configurations incorporate the benefits of both fixed wing and VTOL aircraft, resulting in aerial vehicles that demonstrate the hovering and infrastructure-free takeoff/landing capabilities inherent to VTOL aircraft, alongside the efficient cruise operation and improved forward flight maneuverability inherent to fixed wing aircraft (Ref. 3). The tailsitter is a class of hybrid UAS that transitions between flight modes via a rigid body rotation, and is of particular interest due to the mechanical simplicity of the transition maneuver (Ref. 4). A specific example of a tailsitter UAV aircraft is the Quadrotor Biplane (QRBP), which incorporates two parallel wing sections mounted under four rotors in a quadrotor configuration (Ref. 5). The specific QRBP design used for this paper is the 3 lb. Common Research Configuration (CRC-3), which is depicted in Fig. 1.

The transition between flight regimes for tailsitter platforms involves complex aerodynamics, so a focus on autonomous guidance and control of the QRBP is vital for practical appli-

Figure 1: **The 3 lb. Common Research Configuration (CRC–3)** (Ref. 6)

cation of these platforms. This has been the focus of prior research efforts, such as in (Ref. 7) where Swarnkar *et al* designed a model-based control architecture based on both a quadrotor and fixed wing model approximation of the QRBP dependent on a mode–switching implementation, wherein different controllers are used to control the QRBP based on critical pitch angle. In (Ref. 8), a control architecture without

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Intelligent Systems: Models and Applications Endre Pap,2012-10-20 The theory and applications of intelligent systems is today an important field of research This book is an up to date collection of seventeen chapters written by recognized experts in the field In an introductory mathematical foundations part an overview of generalizations of the integral inequalities for nonadditive integrals and a construction of the General Prioritized Fuzzy Satisfaction Problem is given Then different aspects of robotics are presented such as the differences between human beings and robots the motion of bipedal humanoid robots and an evaluation of different autonomous quadrotor flight controllers Also Fuzzy Systems are presented by a model of basic planar imprecise geometric objects allowing various applications in image analysis GIS and robotics as well as a type 2 fuzzy logic in a software library for developing perceptual computers and a two degree of freedom speed control solutions for a brushless Direct Current motor The book also presents recent applications in medicine such as a Virtual Doctor System methods for a face to face human machine interaction and an emotion estimation with applications for multiple diseases and the effect of the applied therapy The last part of the book covers different applications in transportation network monitoring and localization of pedestrians in images   Deep Learning for Unmanned Systems Anis Koubaa,Ahmad Taher Azar,2021-10-01 This book is used at the graduate or advanced undergraduate level and many others Manned and unmanned ground aerial and marine vehicles enable many promising and revolutionary civilian and military applications that will change our life in the near future These applications include but are not limited to surveillance search and rescue environment monitoring infrastructure monitoring self driving cars contactless last mile delivery vehicles autonomous ships precision agriculture and transmission line inspection to name just a few These vehicles will benefit from advances of deep learning as a subfield of machine learning able to endow these vehicles with different capability such as perception situation awareness planning and intelligent control Deep learning models also have the ability to generate actionable insights into the complex structures of large data sets In recent years deep learning research has received an increasing amount of attention from researchers in academia government laboratories and industry These research activities have borne some fruit in tackling some of the challenging problems of manned and unmanned ground aerial and marine vehicles that are still open Moreover deep learning methods have been recently actively developed in other areas of machine learning including reinforcement training and transfer meta learning whereas standard deep learning methods such as recent neural network RNN and coevolutionary neural networks CNN The book is primarily meant for researchers from academia and industry who are working on in the research areas such as engineering control engineering robotics mechatronics biomedical engineering mechanical engineering and computer science The book chapters deal with the recent research problems in the areas of reinforcement learning based control of UAVs and deep learning for unmanned aerial systems UAS The book chapters present various techniques of deep learning for robotic applications The book chapters contain a good literature survey with

a long list of references The book chapters are well written with a good exposition of the research problem methodology block diagrams and mathematical techniques The book chapters are lucidly illustrated with numerical examples and simulations The book chapters discuss details of applications and future research areas **Robotics Research** Masayuki Inaba,Peter Corke,2016-04-22 This volume presents a collection of papers presented at the 16th International Symposium of Robotic Research ISRR ISRR is the biennial meeting of the International Foundation of Robotic Research IFRR and its 16th edition took place in Singapore over the period 16th to 19th December 2013 The ISRR is the longest running series of robotics research meetings and dates back to the very earliest days of robotics as a research discipline This 16th ISRR meeting was held in the 30th anniversary year of the very first meeting which took place in Bretton Woods New Hampshire USA in August 1983 and represents thirty years at the forefront of ideas in robotics research As for the previous symposia ISRR 2013 followed up on the successful concept of a mixture of invited contributions and open submissions 16 of the contributions were invited contributions from outstanding researchers selected by the IFRR officers and the program committee and the other contributions were chosen among the open submissions after peer review This selection process resulted in a truly excellent technical program which featured some of the very best of robotic research These papers were presented in a single track interactive format which enables real conversations between speakers and the audience The symposium contributions contained in this volume report on a variety of new robotics research results covering a broad spectrum organized into traditional ISRR categories control design intelligence and learning manipulation perception and planning **Neural Computing for Advanced Applications** Haijun Zhang,Kim Fung Tsang,Fu Lee Wang,Tianyong Hao,Zenghui Wang,Zhou Wu,Zhao Zhang,Kevin Hung,2025-11-12 This two volume set CCIS 2664 and 2665 constitutes the refereed proceedings of the 6th International Conference on Neural Computing for Advanced Applications NCAA 2025 held in Hong Kong China during July 4 6 2025 The 62 full papers presented in these proceedings were carefully reviewed and selected from 160 submissions The papers are organized in the following topical sections Part I Neural network NN theory NN based control systems neuro system integration and engineering applications Deep learning driven pattern recognition computer vision and its industrial applications Part II Natural language processing knowledge graphs recommender systems and their applications Neural computing based fault diagnosis and forecasting prognostic management and cyber physical system security Sequence learning for spreading dynamics forecasting and intelligent techniques against epidemic spreading Multimodal deep learning for representation fusion and applications Workshop session International Conference on Cognitive Intelligence ICCI **Motion Control** Federico Casolo,2010-01-01 The book reveals many different aspects of motion control and a wide multiplicity of approaches to the problem as well Despite the number of examples however this volume is not meant to be exhaustive it intends to offer some original insights for all researchers who will hopefully make their experience available for a forthcoming publication on the subject **Computer Vision Systems** Ming Liu,Haoyao Chen,Markus

Vincze,2017-10-10 This book constitutes the refereed proceedings of the 11th International Conference on Computer Vision Systems ICVS 2017 held in Shenzhen China in July 2017 The 61 papers presented were carefully reviewed and selected from 92 submissions The papers are organized in topical sections on visual control visual navigation visual inspection image processing human robot interaction stereo system image retrieval visual detection visual recognition system design and 3D vision fusion *Experimental Robotics* Oussama Khatib,Vijay Kumar,Gaurav Sukhatme,2013-08-20 Incorporating papers from the 12th International Symposium on Experimental Robotics ISER December 2010 this book examines the latest advances across the various fields of robotics Offers insights on both theoretical concepts and experimental results **Delays and Networked Control Systems** Alexandre Seuret,Laurentiu Hetel,Jamal Daafouz,Karl H. Johansson,2016-06-07 This edited monograph includes state of the art contributions on continuous time dynamical networks with delays The book is divided into four parts The first part presents tools and methods for the analysis of time delay systems with a particular attention on control problems of large scale or infinite dimensional systems with delays The second part of the book is dedicated to the use of time delay models for the analysis and design of Networked Control Systems The third part of the book focuses on the analysis and design of systems with asynchronous sampling intervals which occur in Networked Control Systems The last part of the book exposes several contributions dealing with the design of cooperative control and observation laws for networked control systems The target audience primarily comprises researchers and experts in the field of control theory but the book may also be beneficial for graduate students **Advances in Intelligent and Autonomous Aerospace Systems** John Valasek,2012 Research advances in embedded computational intelligence communication control and new mechanisms for sensing actuation and adaptation hold the promise to transform aerospace The result will be air and space vehicles propulsion systems exploration systems and vehicle management systems that respond more quickly provide large scale distributed coordination work in dangerous or inaccessible environments and augment human capabilities Advances in Intelligent and Autonomous Aerospace Systems seeks to provide both the aerospace researcher and the practicing aerospace engineer with an exposition on the latest innovative methods and approaches that focus on intelligent and autonomous aerospace systems The chapters are written by leading researchers in this field and include ideas directions and recent results on intelligent aerospace research issues with a focus on dynamics and control systems engineering and aerospace design The content on uncertainties modeling of large and highly non linear complex systems robustness and adaptivity is intended to be useful in both the sub system and the overall system level design and analysis of various aerospace vehicles A broad spectrum of methods and approaches are presented including Bio Inspiration Fuzzy Logic Genetic Algorithms Q Learning Markov Decision Processes Approximate Dynamic Programming Artificial Neural Networks Probabilistic Maps Multi Agent Systems Kalman particle and confidence filtering **Applying a Reachability-based Controller Synthesis Algorithm on an Autonomous Quadrotor Helicopter Testbed** Eugene

Li,2010   *Agile Autonomy: Learning High-Speed Vision-Based Flight* Antonio Loquercio,2023-04-24 This book presents the astonishing potential of deep sensorimotor policies for agile vision based quadrotor flight Quadrotors are among the most agile and dynamic machines ever created However developing fully autonomous quadrotors that can approach or even outperform the agility of birds or human drone pilots with only onboard sensing and computing is challenging and still unsolved Deep sensorimotor policies generally trained in simulation enable autonomous quadrotors to fly faster and more agile than what was possible before While humans and birds still have the advantage over drones the author shows the current research gaps and discusses possible future solutions   *Deep Reinforcement Learning for Aggressive Quadrotor Maneuvers* □□□,2023   *Guaranteeing Safe Online Machine Learning Via Reachability Analysis* Jeremy H. Gillula,2013 Reinforcement learning has proven itself to be a powerful technique in robotics however it has rarely been employed to learn in a hardware in the loop environment due to the fact that spurious training data could cause a robot to take an unsafe and potentially catastrophic action This thesis proposes a method for overcoming this limitation known as Guaranteed Safe Online Learning via Reachability GSOLR in which the control outputs from the reinforcement learning algorithm are wrapped inside another controller based on reachability analysis that seeks to guarantee safety against worst case disturbances After defining the relevant backwards reachability constructs and explaining how they can be calculated the thesis formalizes the concept of GSOLR and shows how it can be used on both a simple simulated inverted pendulum example and a non simulated target tracking problem in which an observing quadrotor helicopter must keep a target ground vehicle with unknown but bounded dynamics inside its field of view at all times while simultaneously attempting to build a motion model of the target Extensions to GSOLR are then presented which allow the safety of the system to automatically become neither too liberal nor too conservative thus allowing the machine learning algorithm running in parallel the widest possible latitude while still guaranteeing system safety These extensions are also demonstrated on the inverted pendulum example as well as a practical example namely that of safely learning an altitude controller for a quadrotor helicopter These examples demonstrate the GSOLR framework s robustness to errors in machine learning algorithms and indicate its potential for allowing high performance machine learning systems to be used in safety critical situations in the future   **Design and Control of an Autonomous Variable-pitch Quadrotor Helicopter** Mark Johnson Cutler,Massachusetts Institute of Technology. Department of Aeronautics and Astronautics,2012 The aerospace community particularly in academia has seen a recent rise in the popularity of fixed pitch quadrotor helicopters The fixed pitch quadrotor is popular largely because of its mechanical simplicity relative to other hovering aircraft This simplicity however places fundamental limits on the achievable actuator bandwidth and the types of maneuvers possible to fly This thesis explores the extent to which the addition of variable pitch propellers to a quadrotor helicopter overcomes these limitations A detailed analysis of the potential benefits of variable pitch propellers over fixed pitch propellers for a quadrotor is presented This analysis is supported with experimental testing to

show that variable pitch propellers in addition to allowing for efficient generation of negative thrust substantially increase the maximum rate of thrust change A nonlinear quaternion based control algorithm is presented for controlling the quadrotor An accompanying trajectory generation method is detailed with an optimization routine for finding minimum time paths through waypoints The control law and trajectory generation algorithms are implemented in simulation and on a custom variable pitch quadrotor The quadrotor attitude control is performed on the vehicle using a custom autopilot Position and attitude measurements are made with an off board motion capture system Several flight tests are shown with a particular emphasis on the benefits of a variable pitch qaudrotor over a standard fixed pitch quadrotor for performing aggressive and aerobatics maneuvers To the best of the author s knowledge this work marks the first documented autonomous variable pitch quadrotor built for agile and aggressive flight   **Stabilization of a Roll-tilt Camera on an Autonomous Quadrotor Helicopter** William Nathan Pickeral,Massachusetts Institute of Technology. Department of Mechanical Engineering,2011 Harmful algal blooms are becoming an increasingly difficult problem to deal with particularly in Singapore The Center for Environmental Sensing and Modeling CENSAM has developed a network of autonomous vehicles to nd blooms when they occur The problem is that finding blooms which are often transient in nature can be difficult particularly with slow moving underwater and surface vehicles Autonomous quadrotor helicopters are being utilized to visually survey large areas to spot these blooms while they are occurring Here we develop a model for implement ing servo motor controlled camera stabilization on these autonomous vehicles The need for camera stabilization arises because video footage is monitored continuously while the onboard GPS is controlling the motion of the quadrotor The operator of the quadrotor may not want to look in the direction that the GPS controller would like to guide the vehicle We explore implementing a system that gives the operator the ability to control the camera yet maintain the autonomous nature of the quadrotor We develop two models for the rotations involved in stabilizing the position and orientation of the camera against the motion of the vehicle it is mounted on We use these models to investigate the limitations this type of active stabilization would im pose on our quadrotor and GPS controller and discuss the next steps in integrating it into our system   **Autonomous Quad Rotor Helicopter Unmanned Aerial Vehicle (UAV)** G. Otto,2008 Final year report Elektriese Elektroniese en Rekenaaringenieurswese

    Autonomous Landing of Quadrotor on a Moving UGV with the Optimal Control Policies Suhas Priyatham Manda,2021 This thesis proposes an offline method that uses an integral reinforcement learning IRL technique along with the system identification to determine the optimal control of a system with completely unknown dynamics Unmanned aerial vehicles UAV that are particularly deployed to track and land on an arbitrarily moving unmanned ground vehicles UGV demand a high performance controller to perform precise tracking One way of designing an optimal tracking controller is developing linear quadratic integrators LQI with a quadratic type of cost function that solves Riccati equation However this approach requires prior knowledge of the linearized UAV system dynamics We overcome this problem by employing an IRL technique that

solves LQI through system identification Usually IRL techniques adopt a conventional way of solving the Hamilton Jacobi Bellman HJB equation with value function approximation The proposed approach evaluates the optimal control using IRL that solves the HJB equation using system identification instead of value function approximation Assuming that the UAV system dynamics are linear time invariant over a particular flight condition we identify the linear model by analyzing the input and output data samples from a linear regression perspective where we use the conjugate gradient descent optimization algorithm This approach addresses the challenge to compute optimal control without the need to know UAV dynamics We have rigorously tested and simulated the proposed method on various flight trajectories The test results have shown significant improvement in the control policy over each iteration of IRL After validating the proposed method in simulation we have implemented this approach on a real UAV to track and land on a UGV **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 Trajectory Tracking and Payload Dropping of an Unmanned Quadrotor Helicopter Based on GS-PID and Backstepping Control Jing Qiao,2018 Two useful control techniques the Gain Scheduled Proportional Integral Derivative GS PID control and backstepping control have been applied by using quadrotor Unmanned Aerial Vehicle UAV in the applications of trajectory tracking and payload dropping operations in this thesis These control algorithms are analyzed and verified through software simulations and experimental tests The dynamic model of the quadrotor UAV is firstly established using Newton Euler laws The quadrotor comes with a symmetric nonlinear and multiple input multiple output MIMO dynamic model The GS PID control algorithm is implemented firstly in take off trajectory tracking payload dropping and landing periods of flight in

trajectory tracking and payload dropping scenarios Unlike other control algorithms that tend to linearize nonlinear systems backstepping works without cancelling the nonlinearities in the system This leads to more flexible designs of the control model The backstepping control is implemented in this thesis for better performance of the quadrotor UAV for the two scenarios as well Both control algorithms are implemented on the parameters of an unmanned quadrotor helicopter platform known as Qball X4 available at the Networked Autonomous Vehicles Lab NAVL of Concordia University Using MATLAB Simulink to build the simulation control model the flight simulation of the Qball X4 is carried out for the trajectory tracking and the payload dropping In order to further investigate these two control approaches the Qball X4 is used for experimental verification on payload dropping performance The results indicate that both algorithms can obtain acceptable performance but the backstepping controller proves to be a better performed one   <u>Design, Construction and Control of a Quadrotor Helicopter Using a New Multirate Technique</u> Camilo Ossa,2012

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