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ROBUST CONTROL OF UNMANNED AERIAL VEHICLE WITH TILT ROTORS AND CAMERA

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Abstract

In this work, we present a UAV with an H-shaped structure with four tilt rotors and equipped with a camera. We develop the complete dynamic model, which is used for numerical simulations. We also design a simplified dynamic model, which is formulated to facilitate the control system design. In the following, we develop a control system to UAV tracks feasible trajectories and orientate the camera, even in the presence of external disturbances and perturbations, such as wind gusts and modeling errors. To control the UAV position, we use the robust H_∞ control technique and a dynamic inverse to compensate for the nonlinearities. To control the UAV attitude, rotors inclination, and camera pointing, we use the Generalized Super-Twisting Algorithm control technique and compensation of the nonlinearities. To analyze the system performance, we realize numerical simulations, where we verified a satisfactory performance.

Keywords: UAV, H-Shaped Quadrotor, Sliding Mode Control, Robust Control

1. Introduction

The use of unmanned aerial vehicles (UAVs) has been shown very advantageous. Since replacing the manned aerial vehicles, we can have a cost reduction and perform previously unfeasible tasks. The UAV we use in this work is the H-shaped quad tilt-rotor, which has the four rotors positioned, forming an H-shape (see Figure 1). With this structure, the UAV has direct actuation in two directions; which allows it to take off and land vertically and move forward/backward without inclining. This structure, which is little explored, shows advantages in tasks requiring high speeds or a coupled tool. An example of a task is surveillance. In this case, besides being composed of vigilant and fixed cameras, it also would have mobile cameras, increasing the coverage area and adding the possibility of following a target. Concerning the system structure, we can couple a camera to the UAV body through a gimbal mechanism, which offers more degrees of freedom for the camera movement. In this work, we use a gimbal with two degrees of freedom, as shown in Figure 1. Also, we can add robust controllers to the whole system, aggregating robustness in situations in which the UAV is exposed to external disturbances.

Concerning the control systems, we found few works related to the H-shaped quad tilt rotor. In [1], is developed a control system for an H-shaped quad tilt rotor equipped with a camera aimed for racing purposes using PID controller, whose gains were tuned through genetic algorithm. Besides, [1] considered the rotors to move equally.

However, for others UAVs structures, we verify in the literature that control systems is a lot explored theme. This can be seen in [2-4], where were realized reviews of control techniques applied in UAVs. In these works, the UAV most used is the quad rotor in X-shape structure. Several control techniques have been used such as PID [5], LQR [6], robust control H_∞ [7], feedback linearization [8-10], backstepping [6,7], sliding mode control (SMC) [11-15], and intelligent control system techniques [14]. After some analysis of the system response, robustness, and control effort, we concluded that, in general, the SMC presented the best performance [2-4].

- Costa, Thamiris; El'Youssef, Ebrahim; De Pieri, Edson “Robust UAV Formation Control.” In: 27th International Congress of Mechanical Engineering, 2023, Florianopolis.



COB-2023-1433 ROBUST UAV FORMATION CONTROL

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Abstract. *The formation control problem consists of formulating a control law capable of maintaining the UAVs at a safe distance from each other, controlling the UAVs in their desired positions during the entire task execution time, and ensuring that the UAVs will not collide with each other. Thus, proposing a solution for the formation control problem involves different technological challenges, implying an active research topic. Then, the work aims to develop a robust formation control based on the robust control H_∞ methodology for a multi-UAV system composed by UAVs with tilt rotors. The approaches used to develop the control system are the leader-follower and consensus. The control law is obtained considering the methodology of the robust control H_∞ . The stability analysis uses the Lyapunov theory through linear matrix inequalities (LMIs). The results were analyzed through numerical simulations considering a multi-UAV composed of two virtual leaders and six followers. In the results, it is possible to verify that the formation could keep the desired shape during the task execution time. Then, the control system proposed could lead to the work objective achievement.*

Keywords: UAVs, Formation control, Robust controller.

1. INTRODUCTION

Unmanned aerial vehicles (UAVs) have been attracting the attention of researchers because of the many advantages they offer in various domains. These aerial robots enable access to locations otherwise unreachable to humans, whether because of security concerns or inaccessibility. While UAV systems already possess inherent advantages, leveraging multiple UAVs collaboratively in the same task brings further benefits, including enhanced fault tolerance, flexibility, and time efficiency.

The study of multi-UAV systems is a prominent research topic that has received extensive attention. These systems are inherently complex and encompass various technological challenges. Developing multi-UAV systems involves addressing decision-making, path planning, control, and communication subsystems. This work specifically focuses on the control aspect. Controlling multi-UAV systems entails managing formation control, which pertains to effectively shaping the UAVs to track desired positions or trajectories.

Various approaches have been employed to address the formation control problem, including virtual-structure (Liu *et al.*, 2019, 2020), leader-follower (Dong *et al.*, 2016; He *et al.*, 2018; Ai and Yu, 2019; Dong *et al.*, 2018; Yan and Ma, 2020; Kartal *et al.*, 2020; Wang *et al.*, 2021), behavior-based (Oh *et al.*, 2017), and consensus methods (He *et al.*, 2018; Liu *et al.*, 2019; Wang *et al.*, 2021).

The virtual-structure approach utilizes a guiding virtual structure to ensure all agents meet formation constraints. Similarly, the leader-follower approach designates a leader to fulfill this role. While both methods require complete information about the virtual structure or leader, respectively, they offer good control capabilities and are widely utilized. However, they need more inflexibility, posing challenges for formation members to navigate around obstacles.

In contrast, the behavior-based strategy establishes desired behaviors for formation agents, including collision avoidance, formation reconfiguration, formation maintenance, and trajectory tracking (Oh *et al.*, 2015; Yang and Hu, 2020). This approach adapts well to environmental changes due to its behavioral foundation. Additionally, the computational complexity remains the same with the addition of more robots since agents do not require global interaction. However, stability analysis becomes complex as this control strategy relies on something other than the system's kinematics or dynamics (Ahn, 2020).

2 Capítulo de livro

- COSTA, Thamiris; EL'YOUSSEF, Ebrahim; DE PIERI, Edson. “Formation Tracking Control of Multiple UAVs in the Presence of Communication Faults. In: Climbing and Walking Robots Conference.” Cham: Springer Nature Switzerland, 2023. p. 251-262.



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Formation tracking control of multiple UAVs in the presence of communication faults

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Abstract. When working in cooperation, multiple Unmanned Aerial Vehicles (Multi-UAVs) systems bring many advantages for task achievement. Among the technology involved in these systems is the control of the system movements. Controlling multi-UAV systems is an emerging topic in robotics and control communities. In the literature, this problem is known as formation control, and it is about managing the UAVs in such a way that they maintain a specific pattern to accomplish an assigned mission. This work proposes a formation control system based on the virtual structure method. We propose a distributed control law that aims to make the UAVs track the virtual-leader trajectory and achieve a consensus with its neighbors. The agents may lose communication with the virtual structure by modeling a control law with parametric uncertainty. Stability analysis uses Linear Matrix Inequalities (LMIs) and considers communication losses with the virtual structure. To verify the system performance, we test different scenarios assuming that the agents lose communication with the virtual structure, keeping only the consensus control law. The results show that the formation control system is stable even in case of loss of communication with the virtual structure.

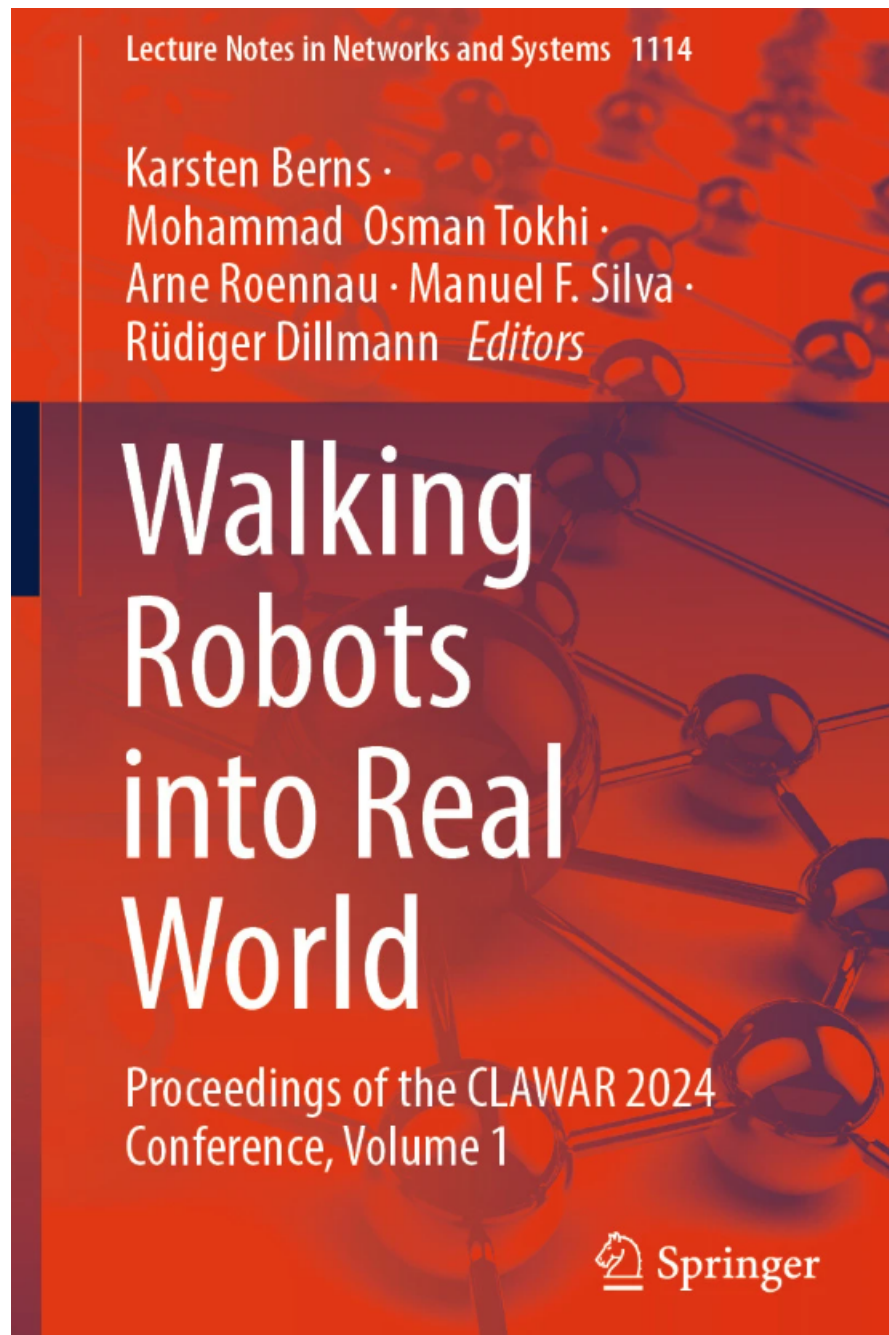
Keywords: UAV, Formation control, LMIs, Parametric uncertainties

1 Introduction

Multi-UAVs systems are composed of multiple UAVs working together to achieve a common goal. In such scenarios, UAVs exhibit collective intelligence from their interactions with neighboring agents. The technology behind swarm systems involves algorithms responsible for task allocation, flight coordination, trajectory planning, and inter-agent communication, which increase system autonomy and reduce human involvement.

Controlling a multi-UAV system involves governing the UAVs to achieve their objectives collaboratively, and its specific formulation depends on task requirements. One requirement is achieving and maintaining the multi-UAV system within a particular structure, known as formation control.

- MELOTTI, Saulo et al. Climbing Robot Inspired by Inchworms: Adaptable for Tubular and Flat Surfaces with Multi-plane Work Capability. In: Climbing and Walking Robots Conference. Cham: Springer Nature Switzerland, 2024. p. 191-203.



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Abstract. In numerous industries, the execution of high-rise tasks necessitates robots equipped with climbing capabilities to reduce human risk exposure (HRE) and meet Environmental, Social, and Governance (ESG) metrics. In response to these demands and drawing inspiration from the climbing behavior observed in animals like inchworms, we have designed an innovative inchworm-like robot. Featuring a 6-degree-of-freedom (DOF) configuration and permanent magnetic adhesion feet, the robot's adhesion is enhanced by the ability to toggle the magnets on and off through magnetic pack rotation. This versatile design enables the robot not only to ascend various surfaces but also to dynamically adjust its working plane—a crucial advantage for navigating tubular environments and scaling truss structures.

Keywords: Inchworm, Bio-inspired Robot, Wall Climbing Robot, Pipe Climbing Robot, ROS

1 Introduction

Climbing robots play a crucial role in tackling tasks that pose risks to human safety in high-altitude and hard-to-reach environments. Their applications span various industries, including bridge inspection, high-rise building cleaning, fruit picking, high-altitude rescue operations, and many others [1].

Extensive research has been dedicated to climbing robots, resulting in numerous experimental models. Key considerations in their design include locomotion and adhesion methods. Adhesion is critical for climbing diverse surfaces, with methods ranging from magnetic and air pressure adsorption to claw grasping and electrostatic adsorption. Meanwhile, locomotion mechanisms are categorized as active, relying on internal power, or passive, utilizing external power sources like hoists and winches. Active locomotion types include wheeled, legged, tracked, inchworm, and hybrid varieties, each offering distinct advantages in maneuverability and versatility [1].

In the realm of construction and infrastructure maintenance, the use of truss-based structures is prevalent in various applications such as communication towers and oil