Modeling and Control of Quadrotor UAVs on SE(3) in Application to Autonomous Docking

A thesis submitted

in partial fulfillment for the award of the degree of

Doctor of Philosophy

by

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June 2025

Abstract

A quadrotor UAV is a multirotor airborne robot distinguished by its mechanical simplicity and usability. These characteristics have accelerated the development of various airborne systems with advanced capabilities and the deployment of quadrotor swarms for cooperative task execution. As the incorporation of multiple UAVs to perform advanced tasks becomes more prevalent, we explore autonomous docking schemes for quadrotors.

Autonomous docking of quadrotors is divided into two phases: the approach phase and the docking phase. The approach phase involves quadrotors navigating toward each other, while the actual docking is achieved in the docking phase. In this thesis, we propose different modeling, guidance, and control schemes for the autonomous docking of quadrotors.

In this work, the dynamics of the UAV is represented using a non-Euclidean space known as Special Euclidean space, SE(3), which employs a rotation matrix and thus overcomes the limitations introduced by other attitude representations. A geometrically accurate discrete model is developed based on the Lie group variational integrator (LGVI) technique. We also propose two distinct trajectory generation schemes. The first generates an optimal energy trajectory for the quadrotor UAV using geometrically exact computations on SE(3) and the nonlinear discrete model, while the second generates sub-optimal trajectories utilizing a model linearized on SE(3). As the approach phase constitutes the substantial period of the entire docking process, it is convenient to adopt an optimal energy trajectory generation scheme as the ones proposed here.

Unlike the approach phase, for the docking phase, we focus more on precision than energy efficiency, and it requires control of the port position and velocity of the quadrotor. We model and control the docking port dynamics using a linear model and a state feedback controller. The linearization is performed on SE(3) which preserves the geometric properties of the system. Along with the linear controller, we develop a geometric nonlinear controller on SE(3) to control the port dynamics. The performance of the controller is analyzed through multiple simulation studies. We extend our study on the control of port dynamics to tiltrotor quadrotors which can effectively decouple translational and rotational dynamics. Being an overactuated system, tiltrotors are suitable candidates for aerial manipulation tasks. We propose a robust sliding mode-based controller for the port trajectory tracking of a tiltrotor quadrotor while following an independent attitude profile. We illus-

trate simultaneous tracking of port and attitude profiles numerically. The proposed port dynamics control schemes can be employed for the docking phase of the quadrotors.

If the final docking point is not specified, the two quadrotors must communicate with each other and maneuver based on each other's instantaneous position and velocity. For such scenarios, we propose an integrated translational and port angle guidance based on artificial potential function for the approach phase to simultaneously meet both the translational and port angle requirements. For the docking phase, we use two different strategies. In the first method, we develop a linearized relative port-to-port model using the relative variables defined for docking requirements. In the second approach, we adopt the nonlinear port dynamics controller on SE(3), which can control the port position precisely, to meet the docking phase requirements. Numerical simulation studies illustrate the efficiency of the proposed guidance and control schemes. We also discuss and demonstrate the docking of tiltrotor quadrotors using the proposed sliding mode controller.