Chapter 20

Back-Stepping Control of Quadrotor: A Dynamically Tuned Higher Order Like Neural Network Approach

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ABSTRACT

The dynamics of a quadrotor is a simplified form of helicopter dynamics that exhibit the same basic problems of strong coupling, multi-input/multi-output design, and unknown nonlinearities. The Lagrangian model of a typical quadrotor that involves four inputs and six outputs results in an underactuated system. There are several design techniques available for nonlinear control of mechanical underactuated system. One of the most popular among them is backstepping. Backstepping is a well known recursive procedure where underactuation characteristic of the system is resolved by defining ‘desired’ virtual control and virtual state variables. Virtual control variables is determined in each recursive step assuming the corresponding subsystem is Lyapunov stable and virtual states are typically the errors of actual and desired virtual control variables. The application of the backstepping even more interesting when a virtual control law is applied to a Lagrangian subsystem. The necessary information to select virtual control and state variables for these systems can be obtained through model identification methods. One of these methods includes Neural Network approximation to identify the unknown parameters of the system. The unknown parameters may include uncertain aerodynamic force and moment coefficients or unmodeled dynamics. These aerodynamic coefficients generally are the functions of higher order state polynomials. In this chapter we will discuss how we can implement linear in parameter first order neural network approximation methods to identify these unknown higher order state polynomials in every recursive step of the backstepping. Thus the first order neural network eventually estimates the higher

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order state polynomials which is in fact a higher order like neural net (HOLNN). Moreover, when these NN placed into a control loop, they become dynamic NN whose weights are tuned only. Due to the inherent characteristics of the quadrotor, the Lagrangian form for the position dynamics is bilinear in the controls, which is confronted using a bilinear inverse kinematics solution. The result is a controller of intuitively appealing structure having an outer kinematics loop for position control and an inner dynamics loop for attitude control. The stability of the control law is guaranteed by a Lyapunov proof. The control approach described in this chapter is robust since it explicitly deals with unmodeled state dependent disturbances without needing any prior knowledge of the same. A simulation study validates the results such as decoupling, tracking etc obtained in the paper.

1. INTRODUCTION

Nowadays helicopters are designed to operate with greater agility and rapid maneuvering, and are capable of work in degraded environments including wind gusts etc. Helicopter control often requires holding at a particular trimmed state, generally hover, as well as making changes of velocity and acceleration in a desired way (T. J. Koo & Sastry). The control of unmanned rotorcraft is also becoming more and more important due to their usefulness in rescue, surveillance, inspection, mapping etc. For these applications the ability of the rotorcraft to maneuver sharply and hover precisely is important.

Like fixed-wing aircraft control, rotorcraft control is also involved in controlling attitude pitch, yaw, and roll- and position, either separately or in a coupled way. But the main difference is that, due to the unique body structure of a rotorcraft, as well as the rotor dynamics, the attitude dynamics and position dynamics are strongly coupled. Therefore, it is very difficult to design a decoupled control law of good structure that stabilizes the faster and slower dynamics simultaneously. On the contrary, for a fixed wing aircraft it is easy to design decoupled standard control laws (B. L. Stevens & Lewis, 2003) with intuitively comprehensible performance. Controllers of good structure are needed for robustness, as well as to give some intuitive feel for the functioning of autopilots, Stability Augmentation System (SAS), and Control Augmentation System (CAS).

The dynamics of a quadrotor (A. Mokhtari, A. Benallegue, & Daachi, 2006; A. Mokhtari, A. Benallegue, & Orlov, 2006; P. Castillo, R. Lozano, & Dzul, 2005a; S. Bouabdallah, A. Noth, & Siegwart, 2004; T. Madani & Benallegue, 2006) are a simplified form of rotorcraft dynamics that exhibit the basic problems including underactuation, strong coupling, multi-input/multi-output design, and unknown nonlinearities. In the quadrotor, the movement is characterized by the resultant forces and moments of four independent rotors. Control design for a quadrotor is quite similar to a rotorcraft; therefore the quadrotor serves as a suitable, more tractable, case study for rotorcraft controls design. In view of the similarities between a quadrotor and a rotorcraft, control design for the quadrotor reveals corresponding approaches for rotorcraft control design. The 6-DOF airframe dynamics of a typical quadrotor involves force and moment dynamics in which the position dynamics often appear as kinematics. Backstepping control is one of the solutions to handle such coupled dynamic-kinematic systems.

There are many approaches such as (C. D. Yang & Liu, 2003; R. Enns & Si, 2000; R. Mahony & Hamel, 2005; V. Mistler, A. Benallegue, & M’Sirdi, 2001) etc. available which reveal different control techniques for rotorcraft models. Popular methods include input-output linearization and backstepping.
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