Global Tracking Control of Quadrotor Based on Adaptive Dynamic Surface Control

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ABSTRACT

This paper presents a global nonlinear tracking control system for a quadrotor unmanned aerial vehicle (UAV) in the presence of underactuation, external disturbances and model uncertainties. Quadrotor systems lack enough independent control inputs to control their entire configuration space directly due to underactuation. The proposed solution is to adopt a cascade feedback technique which divides the system into two subsystems: an inner-loop and an outer-loop that form the attitude and position dynamics, respectively. The proposed controller is developed directly on the special Euclidean group with a region of

attraction covering the configuration space, globally. It guarantees the asymptotical convergence of tracking error in the presence of external disturbances and model uncertainties without a priori knowledge of their bounds. The stability of the proposed controller is proven using a Lyapunov function. In particular, the control method combines three techniques: a second order sliding mode control (SMC), a dynamic surface control (DSC), and non-parametric adaptation mechanism. The SMC is used to guarantee the stability of the internal dynamics (the position dynamics) by generating a proper attitude command for the attitude controller. The DMC control guarantees the attitude dynamics stability globally and tracking performance while avoiding the mathematical complexities associated with the highly nonlinear dynamics. The adaptation mechanism includes a radial basis function neural network (RBFNN) to observe uncertainties without the need for prior training. The uncertainties considered include unmodeled dynamics, external disturbances, and parameter uncertainties in mass and inertial matrices as well as motor coefficients. The desirable features of the proposed control system are illustrated by both numerical simulation and experiments on a UAV testbed.

CONCLUSIONS

A robust adaptive control system is designed for quadrotors to follow a desired path despite the system's underactuation, external disturbances and model uncertainties (Figure 1). The proposed attitude controller is based on dynamic surface control and developed directly on the special Euclidean group with a region of attraction covering the entire configuration space. The proposed controller uses adaptive RBFNNs to overcome model uncertainties and external disturbances. The RBFNN is based a single hidden layer to reduce the computational complexity of the control system. This will allow the controller to maintain both dynamic stability and tracking performance while avoiding the singularity associated with orientation representations. The performance of the proposed controller was compared to two other approaches: a traditional PID controller used typically in the off-the-shelf solutions and a state-of-the-art solution proposed by Goodarzi et al in [1]. The results show that the proposed control outperforms those two approaches in terms of both the accuracy and convergence rate. The stability of the control system is proven using a Lyapunov function. The performance of the proposed control system has been validated by both simulation and experiments using 3 DOF testbed. Real flight tests will be the topic of future studies. In an uncontrolled environment, the system may be subject to unexpected and unknown disturbances. Thus, one future direction can be to validate the proposed algorithm against the unmodeled dynamics in 6 degrees of freedom. Although the attitude dynamics, which have been experimentally tested in this work, have more influence on the stability of the system in comparison to translational dynamics, real-flight validation tests can still be helpful. Another future direction can be in terms of simplifying the procedure of identifying the control parameters. Although the proposed control system uses adaptive techniques to compensate for system uncertainties, several tests are still required to find the most suitable control parameters. One solution to that could be using model-reference adaptive control in conjunction with the dynamic surface control in the attitude controller. This will contribute to a consistent system behavior regardless of the actual system parameters with fewer tests.

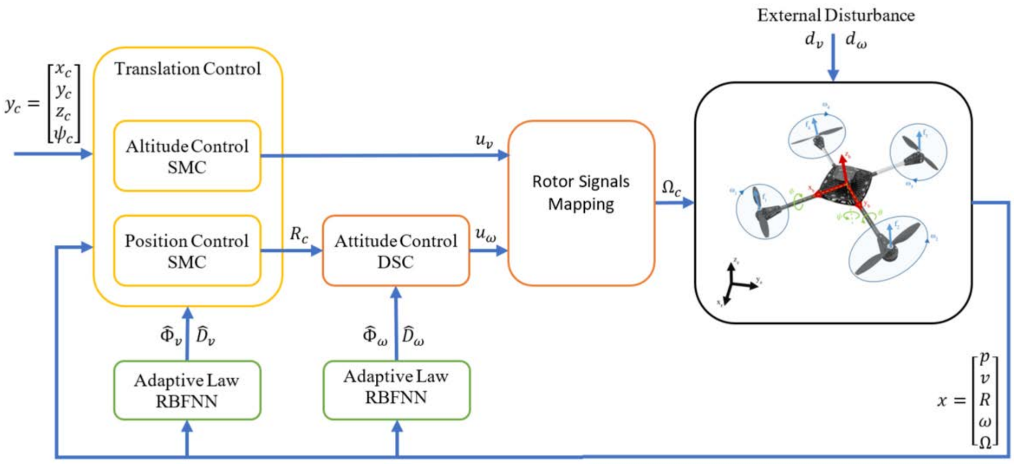

Figure 1 - Block Diagram of the control system. The outer loop assigns a rotation command R_c and control signal u_v from the command signal of position and heading angle. The inner loop controls the under actuated dynamics u_ω. The rotor control takes the input signal and control the rotor speed by generating a proper signal command Ω_c. The Adaptive laws estimate the disturbances $\hat{D}_v$, $\hat{D}_\omega$ and unkown parameters $\hat{\phi}_v$, $\hat{\phi}_\omega$.

[1] Goodarzi FA, Lee D, Lee T. Geometric control of a quadrotor UAV transporting a payload connected via flexible cable. International Journal of Control, Automation and Systems. 2015 Dec;13(6):1486-98.