

Abstract

This thesis deals with the design and analysis of stabilizing singularity free hierarchical nonlinear control for a quadrotor system and a quadrotor equipped with a robotic arm aka quadrotor manipulation system (QMS). A two-fold contribution is made to nonlinear analysis and synthesis of control hierarchy applied to a quadrotor maneuver and subsequently to a QMS under free-light conditions or a QMS undergoing physical interactions with the environment. It is well understood that the underactuated quadrotor system involves position and attitude dynamics in cascade. The initial works study the hierarchical nonlinear control strategy of a quadrotor which requires reference attitude extraction from the designed position control input to derive the attitude control law. However, they typically do not provide the singularity-free desired attitude calculation unless the position control input is bounded. It is found that the widely used saturated position control designs are not smooth enough for the subsequent attitude control development based on the hierarchical procedure. Moreover, attitude singularity often occurs during attitude tracking if the pitch constrained attitude control design is not enforced. In this case, the computed control input may be unbounded. Since the attitude controller doesn't have an infinite bandwidth, the attitude tracking error introduces a strong nonlinear coupling between the position and attitude dynamics. Its effect on stability of the overall system is typically not analyzed in the current literature. In this thesis, a saturation control scheme using hyperbolic tangent function is designed for the position control in order to ensure nonsingular command attitude extraction. A pitch constrained attitude control using barrier Lyapunov function (BLF) with an initial condition constraint is proposed to obviate the problem of attitude singularity during attitude tracking. Another concern is that tracking control of a quadrotor is degraded on interaction with the physical environment using an attached robotic arm / manipulator. This happens due to changes in the inertia parameters. This work introduces adaptive hierarchical attitude control in order to establish robust tracking performance in presence of parameter uncertainties. A multistage constructive procedure with rigorous stability analysis, considering the effect of nonlinear coupling between the two subsystems, has been synthesized at every stage of nonlinear hierarchical control design of a quadrotor system. Furthermore, the main effects that appear and make the dynamic behavior of the QMS different from the standard quadrotor, is the dynamic reaction forces and torques generated by the movement of the arm as well as impact forces while making contact with the physical object. Since QMS is a complex multibody system, this part of the work extends the previously designed nonlinear hierarchical control and applied on position, attitude and manipulation subsystems together considering its coupled dynamic behaviour and environment interaction aspects. The pitch constraint attitude control design is adopted to address the singularity problem which may otherwise severely affect the stability of the QMS while the manipulator end effector trying to make contact with the stationary or dynamic object via impact collision.