Unified Position-Attitude Control of A Nonlinear Quadrotor Swarm

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Abstract: Over the past decade, quadrotor swarms have been widely adopted in applications such as inspection and transportation due to their agile and cooperative maneuverability. Owing to their nonlinearity, underactuation, and limited battery life, computationally efficient control of a nonlinear quadrotor swarm with collision avoidance remains an open field. According to a 2019 survey of over 800 papers, most quadrotor control methods employ a cascaded position-attitude control framework. Such decomposed control of the inherently coupled translation and rotation of quadrotors may be questionable when subjected to constraint drifts caused by numerical integration errors or exogenous disturbances. Moreover, approximately 400 papers adopt linearized quadrotor dynamics, applicable only to small rolls and pitches, in controller synthesis. This linearization may be void in handling scenarios where acrobatic maneuvers are demanded to avoid collisions within a swarm.

We propose a computationally efficient nonlinear control framework for general constrained dynamical systems based on a generalization of Gauss's Principle of Least Constraint (GPLC) that allows for higher-order system dynamics and that dynamically identifies, incorporates, and stabilizes the time-varying set of active constraints. In essence, the GPLC-based control arises from solving a Karush-Kuhn-Tucker system at each time step such that the active constraints are stabilized via user-specified natural frequencies and damping ratios according to a generalized Baumgarte's constraint stabilization. The GPLC-based control actions are the globally optimal solution (with respect to the chosen natural frequencies and damping ratios) that minimizes the quadratic form of the difference between the true constrained highest-order derivatives and the unconstrained ones.

The proposed method is applied to the unified control of the positions and attitudes of multiple nonlinear quadrotors. Numerical results are presented for up to 80 nonlinear quadrotors following a conic spiral virtual leader and eight nonlinear drones swapping positions on a circle, at a computation time order of 100 and 10 microseconds, respectively.

To the best of our knowledge, our work is the first to generalize and to apply GPLC to control a general constrained dynamical system (in terms of system dynamics order and constraint type); it is also the first to generalize constraint error stabilization; and it is the first to unify position-attitude control in one step for multiple nonlinear quadrotors.

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