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Dynamic Control and Singularities of Rigid Bearing-Based Formations of Quadrotors

This thesis studies a.type of group behaviour, moving in formation, for underactuated multirotor unmanned aerial vehicles (UAVs) which have risen in popularity due to low price, high agility, and steady hovering. In particular, we treat the case of multirotors without access to absolute localization, and which detect one another by bearing measurements, which are extractable from onboard cameras. Previous works on UAV bearing formations have resulted in controllers that are effective at low speeds and accelerations, considering UAVs as simple single integrators. This however ignores the complex lower-level dynamics of the UAVs, and therefore these controllers are not necessarily efficient for aggressive formation convergences and manoeuvring.

In this thesis, we present two new control methods based on second order visual servoing (SOVS) and model predictive control (MPC) that take into account increasingly complex robot models, and which are shown through experiments and extensive simulations to outperform existing methods. Experiments show that these controller can maintain the desired formation at speeds exceeding 5 m/s and horizontal accelerations in excess of 10 m/s/s. Additional controller attributes such as numerical conditioning, local minima, and the incorporation of measurement and environmental collision constraints are studied.

The second main contribution of this thesis is a detailed analysis of the degenerate embeddings (or "singularities") of rigid bearing formations. If a formation is rigid then the shape is uniquely defined by the local inter-robot measurements, otherwise there are uncontrolled relative motions between the UAVs and the desired shape may not be guaranteed. This thesis presents what is (to the best of our knowledge) the first systematic geometric analysis of these singular embeddings, using the "hidden robot" concept to express the robot constraints and measurements as a set of constraints limiting the possible kinematic motion of the quadrotors. A set-based contraction of constraint is applied to find the singularities of formations of 20-30 robots, and we show how by respecting certain constraints in the design of formations, we can find a class of arbitrarily large formation graphs for which all singularities are known, and may thus be avoided, guaranteeing the rigidity of the formation.

Mots-clés : Unmanned Aerial Vehicles, Quadrotors, Formation control, Multi-robot systems, Vision-based control, Singularities, Bearing rigidity