Master’s Thesis Defense Announcement
Mechanical and Aerospace Engineering Department
University of Texas at Arlington

A Rigid Body Framework for Modeling and Simulation of Formations of Autonomous Agents

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1PM, Thursday, November 9, 2023
Location: Woolf Hall 200

Abstract

Formation motion, wherein multiple agents operate within close proximity while maintaining precise relative positions and coordinated movements has a significant impact in the realm of Uncrewed Aerial Systems (UAS). Formation establishment, and stationkeeping have been critical research areas as several missions can be conceived and accomplished by groups of “simple” autonomous agents. Advances in this research have led to multiple advantages in areas such as reconnaissance, aerospace exploration, map building, search and rescue, etc. particularly, if the formation motion is inspired by nature and natural phenomena such as flock of birds, school of fish, hydrodynamics (smooth streamlines), magnetic fields, and electrical charges. In such formulations, the formation motion is often captured by a few rules, which are collision avoidance, velocity matching, and flock centering. Besides the examples seen in nature, our research is motivated by the characteristics of a rigid body. By considering the autonomous agents as fixed nodes on a rigid body, the trajectory of each agent on the rigid body is automatically determined based on the behavior and motion of the rigid body itself. Therefore, there is no need to design their trajectories individually. Moreover, since distances between agents are held constant, collision free trajectories are automatically determined. We call this a Virtual Rigid Body (VRB) formation as there is no physical rigid connection between agents, and the virtual rigidity between agents is accomplished via constraint forces.

The main contributions of this research are thorough mathematical modeling, control law development, and simulation of this VRB framework for formation motion. The thesis synthesizes the 6-DOF equations of motion associated with the framework for an arbitrary number of autonomous agents. Reference motion is prescribed for the aggregated rigid body – velocity of the center of mass and the angular velocity. Using these and the rigid body structure specification, local trajectories are calculated to perform the formation establishment. The thesis also develops local control laws for each agent using linear quadratic control methods, designed to ensure formation establishment, and stationkeeping. Extensive simulations within an artificial environment are performed to illustrate the effectiveness of the modeling framework. Several candidate situations are considered such as – formation establishment, reconfiguration, re-orientation, and station-keeping.