Autonomous Strategic Aircraft Deconfliction in a Multi-Vehicle Low Altitude Urban Environment

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Abstract : With the envisioned future growth of low altitude urban aircraft operations for airborne delivery service and advanced air mobility, strategies to coordinate and deconflict aircraft flight paths must be prioritized. Autonomous coordination and planning of flight trajectories is the preferred approach to the future vision in order to increase safety, density, and efficiency over manual methods employed today. Difficulties arise because any conflict resolution must be constrained by all other aircraft, all airspace restrictions, and all ground-based obstacles in the vicinity. These considerations make pair-wise tactical deconfliction difficult at best and unlikely to find a suitable solution for the entire system of vehicles. In addition, more traditional methods which rely on long time scales and large protected zones will artificially limit vehicle density and drastically decrease efficiency. Instead, strategic planning, which is able to respond to highly dynamic conditions and still account for high density operations, will be required to coordinate multiple vehicles in the highly constrained low altitude urban environment. This paper develops and evaluates such a planning algorithm which can be implemented autonomously across multiple aircraft and situations. Data from this evaluation provide promising results with simulations showing up to 10 aircraft deconflicted through a relatively narrow low-altitude urban canyon without any vehicle to vehicle or obstacle conflict. The algorithm achieves this level of coordination beginning with the assumption that each vehicle is controlled to follow an independently constructed flight path, which is itself free of obstacle conflict and restricted airspace. Then, by preferencing speed change deconfliction maneuvers constrained by the vehicles flight envelope, vehicles can remain as close to the original planned path and prevent cascading vehicle to vehicle conflicts. Performing the search for a set of commands which can simultaneously ensure separation for each pair-wise aircraft interaction and optimize the total velocities of all the aircraft is further complicated by the fact that each aircraft's flight plan could contain multiple segments. This means that relative velocities will change when any aircraft achieves a waypoint and changes course. Additionally, the timing of when that aircraft will achieve a waypoint (or, more directly, the order upon which all of the aircraft will achieve their respective waypoints) will change with the commanded speed. Put all together, the continuous relative velocity of each vehicle pair and the discretized change in relative velocity at waypoints resembles a hybrid reachability problem - a form of control reachability. This paper proposes two methods for finding solutions to these multi-body problems. First, an analytical formulation of the continuous problem is developed with an exhaustive search of the combined state space. However, because of computational complexity, this technique is only computable for pairwise interactions. For more complicated scenarios, including the proposed 10 vehicle example, a discretized search space is used, and a depth-first search with early stopping is employed to find the first solution that solves the constraints.

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