Simulating Shared Airspace for Service UAVs with Conflict Resolution

Robotics Track

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ABSTRACT

In future UAV-based services, UAV fleets will be managed by independent service providers in shared low-altitude airspace. Therefore, Conflict Detection and Resolution (CDR) methods that solve conflicts, i.e. possible collisions, between UAVs of all service providers are a key element of the Unmanned Aircraft System Traffic Management (UTM) system. We present a top-to-bottom algorithmic system with an extension to UAV operations of ORCA, a state-of-the-art algorithm in robotics. Then, using extreme-conflict situations, we empirically determine optimal parameter values for our adapted ORCA, and we observe a better performance compared to the standard use of ORCA. Finally, using realistic UAV traffic situations for delivery, we perform extensive simulations to study the potential occurrence and distribution of collisions, and to assess safety parameters for CDR.

KEYWORDS

UAV coordination; UTM; Conflict Detection and Resolution

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1 INTRODUCTION

One of the preconditions for the successful real-world deployment of Unmanned Aerial Vehicle (UAV) fleets is the development of safe and efficient Unmanned Aircraft Systems (UAS) Traffic Management (UTM) systems [6]. In the near future, several operators will task multiple UAVs with limited capacities to visit specific locations, and operate in shared low-altitude and possibly high-density airspace. For this purpose, the path of each UAV must avoid *static* obstacles, such as terrain elevation and no-fly zones, and *dynamic* obstacles, such as other UAVs controlled by other operators. Here, we focus on a partly simplified setting in terms of UAV types, with one model of quadcopter from which we provide realistic flight parameters. We developed a simulator with the following components which is the global context considered:[1] UAS Service Providers (UASSPs) which are used by UAS operators for task allocation and path planning of UAVs given service requirements, and Core UTM that hosts the CDR service to which all UASSPs connect.

The design of CDR approaches is key in the conception of a UTM system [4]. We conduct simulations of a real world environment in Japan with realistic settings in terms of demand for UAVs and task locations. The scenarios we consider in this paper are mainly the use of UAVs for delivery of goods from different UASSPs, including commercial and public services. In this context, several research works [1, 5, 8] proposed a coupling of task allocation and path planning for UAVs. Yet, they do not address collision avoidance between moving UAVs. Moreover, those works only consider a 2D context, thus assuming UAVs keep a constant altitude. By contrast, we take into consideration 3D elements, based on a realistic elevation map. Our contribution is to advance CDR technology by adapting the Optimal Reciprocal Collision Avoidance (ORCA) [9] algorithm to the specific context of UAV fleets, and to report simulated data based on a realistic configuration in terms of scale, terrain and trajectories.

We present a two-stage approach to UAVs delivery operations in shared airspace with an extension of the ORCA algorithm in 3D. In the *pre-flight phase*, for each fleet of UAVs connected to an UASSP, paths are planned to avoid collisions with static obstacles, such as terrain elevation and no-fly zones. In this step, we do not consider the possibility of conflicts, even within each fleet of UAVs. Then, in the *in-flight phase*, as a standard approach in UTM [4], to avoid mutual collisions, the CDR method modifies the initial trajectories for all UAVs of all fleets.

2 TASK ALLOCATION AND FLIGHT PATH GENERATION

Due to both scalability considerations and overhead of operators' definition, an optimal planner is not necessary. To improve the efficiency of computations, we apply a first step of pruning unlikely allocations with a soft clustering approach [2]. A cluster for each

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[1] This context is also realistic in terms of current regulatory environment

UAV of a fleet, is considered as a subset of the most eligible tasks relying on straight line distance. The centroid of each cluster corresponds to each UAV initial location. For each pair of locations of the same cluster, we compute all paths with Theta*[7] and their associated costs. We use a generated elevation map, so each node in the grid contains its latitude, longitude, and elevation. No-fly zones can be incorporated by putting an infinite cost in the evaluation function. Then, we apply Tabu Search [3], a metaheuristic which efficiently solves large sized optimization problems to determine the sequence of tasks for each UAV compatible with their payload and battery life.

3 ADAPTED ORCA

We propose to improve over Standard ORCA's assumptions to make it compatible to real-world UAV deployment in in-flight phase.

Separation distance: Each UAV is surrounded by an imaginary region defined as a sphere of radius r and center position p. This sphere defines a minimum safe separation distance $sep\_dist = 2r$ between two UAVs. Moreover, we define a realistic value of r to guarantee 0% *physical* collisions, as a redundancy mechanism, considering the possible navigation errors of UAVs as in Fig.1. Then, a *collision* is considered as a violation of the defined value of sep_dist between two UAVs and a *conflict* is a predicted collision.

Conflict Detection phase: Standard ORCA is applied at each time step from the start location to the goal location of each agent, whether an agent is in conflict or not. If the agent is not in conflict it returns the same velocity as the current velocity, and if the agent is in conflict it returns a new velocity vector that is guaranteed to be collision-free for the given time window τ. So, we propose to trigger conflict resolution only when a conflict is predicted. This assumes that a UAV will keep its current velocity during the fixed time window τ, which is generally the case as delivery UAVs tend to travel at constant speeds for most of their flight. In case of conflict, the velocity computed by ORCA is transmitted via LTE at a fixed rate to the given UAVs to avoid a collision in τ time steps, else nothing is transmitted and the UAV keeps its current velocity.

Conflict Resolution phase: While conflict detection runs permanently, conflict resolution is a conditional event triggered by conflict detection. The start of the conflict resolution step is dependent on the fixed dec_dist parameter which defines the distance from where a UAV will receive ORCA velocities to change its original trajectory in case of conflict. When the velocity computed by ORCA v_{ORCA} for a UAV in conflict becomes sufficiently close to the preferred velocity v_{pref}, the conflict is declared as solved. In order to avoid an oscillating behaviour between non-conflict and in-conflict states, this comparison can only be done after an arbitrarily fixed number of ORCA iterations. Then, an end waypoint is computed and transmitted to the given UAV to reconnect to its initial path.

Standard ORCA provides fair deviation between all agents in conflict. However, UAVs have take-off and landing phases, and as a rule in airspace, UAVs cannot be deviated during those phases. In this case, the UAV which is in in-flight state takes full responsibility to avoid a collision. For this purpose, the value of the reciprocity coefficient $\lambda \in [0; 1]$ in ORCA, which constrains the set of permitted velocities when computing the solution velocity v_{ORCA} for a UAV, is dynamically changed depending on the state of the UAV.

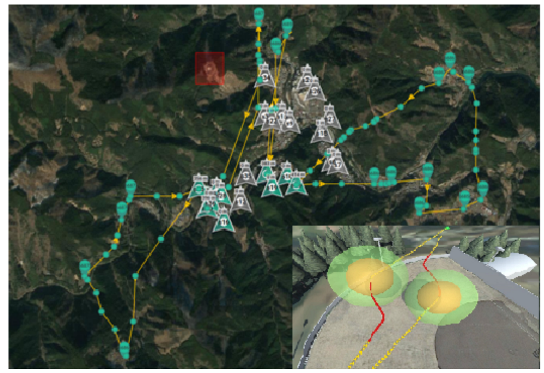

Figure 1: Example of task allocation for one UASSP and example of Adapted ORCA solving a conflict between 2 UAVs. The different safety layers spheres around each UAV are represented in yellow and green. Paths modified by Adapted ORCA are represented in red.

4 SIMULATION STUDIES

In order to assess the potential of a real world deployment of our CDR approach, we developed a simulation platform to simulate realistic service UAVs operations. We propose experimental scenarios based on a real world setup of a given region in Japan as shown in Fig.1. We chose a rural area of around $2 \times 4\ km^2$, it is a more likely candidate for UAV-based services, since airspace in urban areas is not available under current legislative requirements. We relied on the actual repartition of the population in the region and information on their possible needs. We performed simulations for 1) extreme-conflict scenarios and 2) realistic scenarios indicative of future delivery service operations. Our extreme-conflict scenarios yielded an empirical evaluation on values for the parameters dec_dist and τ influencing the performance of our Adapted ORCA, in terms of deviation from the initial path. Those values can be reused in similar context to optimize the performance of our CDR method. These results further indicate the efficiency of our Adapted ORCA over Standard ORCA. In our realistic scenarios, several UASSPs are in the same area, each in charge of their own fleet of UAVs. We fix each UAV capacity (26 min of maximum flight duration as a lower bound with a maximum speed of 5m/s), and maximum payload (1kg), as defined by current quadcopters specifications. The telemetry update time step is fixed at 0.2s. We add the constraint that two UAVs' initial locations and tasks locations cannot be closer to each other less than the defined sep_dist. During the simulations, batches of tasks among the possible locations were randomly generated for each fleet at fixed time intervals. We ran 100 simulations samples for each experiment. Each simulation represented a 4-hour service scenario. Those realistic scenarios allowed us to evaluate the frequency and severity of collisions varying the radius r value. Thus, we assessed our CDR method under realistic circumstances.

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