Automating Bird Diverter Installation through Multi-Aerial Robots and Signal Temporal Logic Specifications

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Abstract—This paper tackles the task assignment and trajectory generation problem for bird diverter installation using a fleet of multi-rotors. The proposed motion planner considers payload capacity, recharging constraints, and utilizes Signal Temporal Logic (STL) specifications for encoding mission objectives and temporal requirements. An event-based replanning strategy is introduced to handle unexpected failures and ensure operational continuity. An energy minimization term is also introduced to handle multi-rotor flight time during installation. Simulations in MATLAB and Gazebo, as well as field experiments, demonstrate the effectiveness and validity of the approach in a mock-up scenario.

I. FULL-VERSION

A full version of this work is available at
https://ieeexplore.ieee.org/document/10197381
To reference, use [1].

II. INTRODUCTION

Power lines are critical infrastructure for supplying energy to millions of people. To enhance network reliability and reduce power outages, installation of bird diverters is crucial to mitigate the risk of bird collisions and improve visibility. However, the current method of using manned helicopters for installation is time-consuming and poses safety risks [2].

Unmanned Aerial Vehicles (UAVs) offer a promising solution for automating and replacing helicopters within the process. UAVs can operate continuously over long distances and can be equipped with lightweight manipulation devices for autonomous operations [3]. However, the limited battery and payload capacity of individual UAVs require the use of multi-UAV teams to expedite the process and cover large-scale scenarios. Planning for a multi-UAV team presents challenges, including scheduling battery recharging, ensuring collision-free trajectories, and considering vehicle dynamics and energy consumption models.

Advanced task and motion planning techniques are necessary to enable bird diverter installation using multi-UAV teams while meeting safety requirements and mission objectives. Signal Temporal Logic (STL), a mathematical framework combining natural language commands with temporal and Boolean operators, can serve this purpose. STL is equipped with a robustness metric, quantifying the extent to which system execution meets requirements [4].

Therefore, this paper introduces a novel approach to task and motion planning for installing bird diverters on power lines using a team of multi-rotors. The proposed method leverages STL to generate optimal trajectories that satisfy mission requirements, considering vehicle dynamics, payload capacity limits, and installation time constraints. To ensure continuous operation, an event-based replanning strategy is introduced to handle unforeseen failures. Additionally, an energy minimization term is integrated to save multi-rotor flight time during installation operations. A hierarchical approach is adopt to handle the complexity of the resulting nonlinear optimization problem. First, a Mixed-Integer Linear Programming (MILP) problem is solved, and the resulting solution is fed into the final STL optimizer.

III. PROBLEM DESCRIPTION

The installation of bird diverters involves visiting specific target regions along upper cables between consecutive towers. The UAVs are assumed to be quadrotors with limited velocity, acceleration, and payload capacity. Ground-based refilling stations along the power line provide diverter reloading. The planning process considers vehicle dynamics, capacity constraints, obstacle avoidance, and safety requirements. The environment map, containing obstacles like power towers and cables, is assumed available before the mission.

IV. PROBLEM SOLUTION

Let us define the state sequence \( x \) and the control input sequence \( u \) for the \( d \)-th multi-rotor as:
\[
\phi = \bigwedge_{d \in D} \bigwedge_{t \in T} \left[ d \phi_{ws} \land d \phi_{obs} \land d \phi_{hm} \right] \land \\
\bigwedge_{t \in T} \bigwedge_{q \in D} \left[ d \phi_{ws}(q) > 0 \right] \land \\
\bigwedge_{d \in D} \bigwedge_{t \in T} \left[ d \phi_{ws}(q) > 0 \right] \\
\bigwedge_{q \in D} \bigwedge_{t \in T} \left[ d \phi_{ws}(q) = 0 \Rightarrow d \phi_{hm}(q) \right] \land \\
\bigwedge_{t \in T} \left[ d \phi_{ws}(q) = 0 \Rightarrow d \phi_{hm}(q) \right] \\
\bigwedge_{d \in D} \bigwedge_{t \in T} \left[ d \phi_{hm}(q) \Rightarrow d \phi_{hm}(j) \right].
\]

\[ (1) \]

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The STL formula \( \varphi \) comprises both safety and task requirements. The safety requirements encompass three aspects: staying within the designated workspace \((d_{ws})\), avoiding collisions with obstacles in the environment \((d_{obs})\), and maintaining a safe distance from other UAVs \((d_{dis})\). On the other hand, the task requirements focus on achieving specific tasks at predefined time intervals during the entire mission time \(T_N\). Firstly, they guarantee that all target regions are visited by at least one UAV \((d_{trv})\). Secondly, they ensure that each UAV remains in a target region for the designated installation time \(T_{inst}\) visits a refilling station, and stays there for a refilling time \(T_R\) once they exhaust their onboard diverters \((d_{trs})\). Finally, after completing their installation operations, each UAV should fly to the nearest refilling station \((d_{tr})\).

The objective function \((4a)\) quantifies the total distance covered by the team. Constraints \((4b)\) and \((4e)\) ensure that each target region is visited exactly once. To achieve this, auxiliary integer variables \(y_{ijd} \in \{0, 1\}\) are introduced, which ensure that if a UAV \(d \in D\) reaches target \(j \in T\), the same UAV must also leave the target. Constraint \((4d)\) guarantees that each UAV starts the mission from its depot and does not return to it. Constraints \((4e)\) serve two purposes: preventing tours that exceed the payload capacity of the UAVs and ensuring that all tours connect to a refilling station, which is commonly known as the sub-tour elimination constraint. The lower bound \(h(T)\) represents the minimum number of UAVs required to visit all target regions \(T\).

As space is limited, we have excluded the mechanism for mission replanning in the event of UAV failures and the enhancement of the motion planner by minimizing energy consumption. For more information on these aspects, please refer to [1].

V. EXPERIMENTAL RESULTS

The effectiveness and validity of the approach are demonstrated through simulations in MATLAB and Gazebo, as well as field experiments carried out in a mock-up scenario. Videos that can be accessed at [http://mrs.felk.cvut.cz/bird-diverter-ar](http://mrs.felk.cvut.cz/bird-diverter-ar).

REFERENCES