Wind-Aware Dubins-Inspired L1 Guidance for Faster Convergence with Bounded Continuous Curvature and Sliding Mode Tracking for UAVs

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1. INTRODUCTION & OBJECTIVE

Unmanned Aerial Vehicles (UAVs) are often required to operate autonomously in many applications, making path planning and control systems essential parts of the autonomous UAV system. These generated trajectories need to be not only time-efficient but also dynamically feasible and robust to disturbances such as wind, while respecting the physical capabilities of the vehicle. Dubins paths [1] provide the time-optimal solution to path following, subject to the minimum turn radius of the UAV in the absence of wind, but these paths are only C^1-continuous. L_1 guidance [2], on the other hand, provides a C^2-continuous path for path following, but takes a long time to converge to the desired path.

This work proposes a novel Dubins-inspired modified L_1 guidance law that first follows the Dubins straight-line segment before converging to the main path using a wind-aware kinematic formulation [3]. The method retains the C^2-continuity of L_1 guidance, respects the minimum turn radius of the UAV, and significantly reduces convergence time, bringing performance closer to the minimum-time solution. To validate dynamic feasibility, the generated trajectories are tracked using a Sliding Mode Controller (SMC) [4] on a 6-DOF quadrotor model.

2. METHODS OF ANALYSIS

The L_1 guidance law is a Virtual Target Point (VTP) based approach in which a lateral acceleration command is generated to guide the vehicle along circular arcs towards the desired path by following a VTP at a constant look-ahead distance L_1. In the proposed approach, the VTP is first moved along the straight-line segment of the Dubins path, which is the time-optimal path in the absence of wind, before transitioning to the desired path. The look-ahead distance L_1 is chosen to respect the minimum turning radius of the UAV. Since L_1 guidance inherently produces C^2-continuous trajectories, the resulting path remains smooth, while also significantly reducing the convergence time, bringing it closer to the minimum time solution. Wind disturbances are explicitly incorporated into the UAV kinematic model by using the ground speed and course angle formulation. The generated trajectories are then supplied as reference inputs to a 6-DOF quadrotor model, where they are successfully tracked using a Sliding Mode Controller (SMC) to demonstrate the dynamic feasibility of the wind-aware guidance law.

3. RESULTS

The proposed guidance and control framework was tested for following straight-line and loiter paths by a quadrotor in altitude-hold mode. Figures 1(a) and 1(b) show the generated paths using the modified L_1 guidance logic, guided by the Dubins straight segment, along with the corresponding SMC-tracked paths with a quadrotor under different constant wind conditions. The results demonstrate that the

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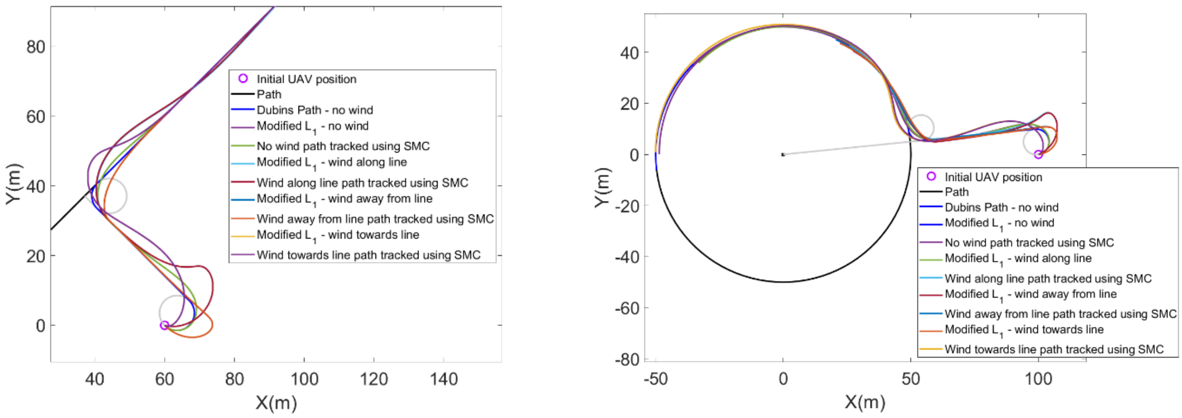
proposed guidance law achieves significantly faster convergence as compared to the traditional L_1 guidance, while maintaining its C^2-continuity and bounded curvature. This improvement arises from initially following the Dubins straight-line segment before transitioning to the main path, thereby avoiding the large detour taken by L_1. The generated trajectories are robustly tracked by a 6-DOF quadrotor model using SMC, validating their dynamic feasibility. Further results, including comparison with standard L_1 guidance, curvature plots, cross-track error plots, and the evolution of course and heading angles, will be presented in the full paper.



(a) (b)

Fig 1: (a) Straight-line and (b) loiter path following with Modified L_1 Guidance under different wind conditions

4. CONCLUSIONS

This work presented a novel Dubins-inspired modified L_1 guidance law for UAV path following in the presence of wind. This approach retained the C^2-continuous nature of the traditional L_1 guidance logic, respects the UAV's minimum turning radius, and achieves significantly faster convergence in comparison to L_1 guidance by first applying L_1 to follow the Dubins straight-line segment, defined without wind, before transitioning to the main path. The guidance law was made robust to wind disturbances by explicitly modelling the UAV kinematics using the course angle and ground speed formulation, which directly incorporates wind effects into the guidance law. These generated wind-aware trajectories were then finally tracked by a 6-DOF quadrotor model using a Sliding Mode Controller (SMC), hence validating the dynamic feasibility of the trajectories.

5. REFERENCES

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