Vector Field Guidance for Autonomous Vehicles

Abstract

This thesis presents novel algorithms on waypoint following, target tracking, obstacle avoidance, collision avoidance and formation control for unmanned vehicles using Lyapunov Guidance Vector Field (LGVF) framework. The primary objective is to enhance the applicability of different autonomous systems consisting of Unmanned Aerial Vehicles (UAVs) and/or Unmanned Ground Vehicles (UGVs) in dull, dirty and dangerous missions.

The first part of the thesis develops C^2 continuous paths with bounded curvature based on the LGVF framework for two-dimensional (2D) waypoint following problems. Faster convergence is ensured as the generation of these paths are based on optimal Dubins paths which are C^1 continuous in nature. To begin with the algorithm is developed for the straight line path convergence and then it is extended to follow a sequence of waypoints by joining any two consecutive waypoints with straight line segments. Then a more challenging version of the algorithms is developed to address the waypoint following in three-dimensional (3D) space. It offers practical solutions to widen the usage of UVs in day to day life, such as automated crop spraying, where coverage area is crucial. The effectiveness of the algorithms is demonstrated through numerical simulations and comparisons with the existing techniques available in the literature. The algorithm is also successfully implemented on a quadrotor in an indoor environment, showcasing its potential for real-world applications.

Next, a guidance algorithm is presented for standoff target tracking by UAVs, employing the Lyapunov guidance vector field framework. Normalized even and odd functions are introduced as circulation and convergence terms for faster convergence. The algorithm generates continuous curvature paths maintaining the bounds on the curvature to make it applicable for fixed-wing UAVs. The effect of wind has also been considered for real-world outdoor applications. Simulation results demonstrate the effectiveness of the proposed guidance law by comparing it with the similar guidance algorithms existing in the literature.

Finally, a singularity-free vector field guidance approach for a swarm of UAVs has been solved for waypoint-following problems in environments filled with static and dynamic obstacles. A novel behavioral-based balance formation topology is introduced, distributing unmanned vehicles evenly within a desired formation circle using a guidance vector field method. The proposed algorithm exhibits asymptotic stability. Its faster convergence compared to existing approaches is demonstrated through comparison with the Barycentric coordinate-based control approach. The proposed formation approach is advantageous as it relies on relative position measurements in local coordinate frames and does not require inter-vehicle communication. Additionally, a proximity-based obstacle avoidance technique is developed, ensuring safe trajectories for each vehicle without encountering singularities. The proposed methodologies are validated through numerical simulations using MATLAB.

To sum up, this thesis provides comprehensive insights into the application of the Lyapunov Guidance Vector Field framework in various unmanned systems, offering practical solutions for waypoint following, target tracking, and obstacle avoidance, collision avoidance, and formation flying. The numerical simulations and real-world implementations highlight the effectiveness and suitability of the proposed algorithms for real-world applications.

Keywords: Lyapunov Guidance Vector Field (LGVF), Unmanned Aerial Vehicles (UAVs), Waypoint-following, Standoff target tracking, Obstacle avoidance, Formation control.