***Title*—Safety-critical fixed-time formation control for UAVs with disturbance based on robust control barrier functions**

***Keywords*—formation control, fixed-time control, control barrier functions, safety-critical control, obstacle avoidance.**

Abstract

This paper focuses on the safety-critical fixed-time formation control for UAVs with disturbance and obstacle collision risk. The control scheme is in a distributed way with the leader's position and velocity being estimated simultaneously by a fixed-time distributed observer. Meanwhile, a disturbance observer that combines fixed-time control theory and sliding mode control is de-signed to estimate the external disturbance. Based on these techniques, we design a nominal control law to drive UAVs to track the desired formation in a fixed time. Regarding obstacle avoidance, we first construct safety constraints using the control barrier functions (CBFs). Then, obstacle avoidance can be achieved by solving an optimization problem with these safety constraints, thus minimally affecting the tracking performance. The main contributions in this process are twofold. First, an exponential CBF is provided to deal with the UAV model with a high-relative degree. Moreover, a robust exponential CBF is designed for UAVs with disturbance, which pro-vides robust safety constraints to ensure obstacle avoidance despite disturbance. Finally, simulation results show the validity of the proposed method.

Main contribution:

(i) A fixed-time distributed observer is designed to estimate the leader's states in a fixed time, compare with the existing results [1-6], it can estimate the position and velocity simultaneously. Also, a disturbance observer combining fixed time control strategy and sliding mode control strategy is designed to estimate the external disturbances, compared with the fixed-time disturbance observer in [7-10], it improves the performance and robustness of the system owing to the use of sliding mode control.

(ii) We propose a CBFs-based safety-critical control method to achieve obstacle avoidance, which can optimize nominal control law via a quadratic program with constraints established using control barrier functions. Compared with control methods in [11-13] that add APFs directly to the control law, the outstanding feature of this method is that the nominal control law is only modified when collision is truly imminent, which guarantees that the tracking performance is minimally affected.

(iii) An exponential CBF is proposed to establish two relative degree safety constraints for UAVs, compared with the existing reduce order method [14-16] and high relative degree CBF constructing method [17], [18], this exponential CBF can ensure the performance and feasibility of the system. Meanwhile, CBFs are based on an accurate model and external disturbance may lead to violation of safety constraints, we combine exponential CBF and min-max inequality to propose robust safety constraints, which can ensure UAV safety despite external disturbance.

Conclusion

In this work, we address the safety-critical fixed-time formation control problem for UAVs with disturbances and obstacle collision threats. First, we design a nominal fixed-time formation control law, in which an elaborate disturbance observer with the sliding mode control strategy is used to estimate the external disturbances. Then, in order to achieve obstacle avoidance and ensure UAVs' safety, we used a CBF-based safety-critical strategy, which can optimize the nominal control law with the constraints constructed using CBFs. Moreover, with some further improvement of the CBF, an exponential CBF is designed so as to provide two relative degree constraints for UAVs. Furthermore, since disturbance may lead to violation of safety constraints, we design robust safety constraints combining the proposed exponential CBF with min-max inequality, which can ensure UAVs' safety despite disturbances. Simulation experiments demonstrate the validity of the proposed method.

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