UAV Swarming with Collision Avoidance and Communication Constraints

Abstract

Collision avoidance is critical for the safe and reliable operation of swarms of UAVs (Unmanned Aerial Vehicles). Numerous works have already been reported in literature. Most of these methods can be grouped into three categories: repulsion, partition-based, and trajectory replanning. In this thesis we seek to further develop some of these existing methods with consideration for special scenarios such as intruder UAV interception and dense UAV traffic coordination, which is a physical constraint often omitted in the design of swarm algorithms. Collision avoidance can be simple to achieve. The challenge is in ensuring that the swarm scenario objectives are not compromised.

The intruder interception problem using UAVs is an interesting problem on its own but also poses a challenge for collision avoidance when multiple agents and intruders are considered. The accessibility of UAV technology motivates us to design a non-destructive method for stopping UAVs that intrude into restricted areas by using our own UAVs to intercept and capture them. For interception, we propose a proportional navigation guidance law, on a double integrator model, for a quadrotor UAV with velocity feedback that globally guarantees interception with non-zero hitting velocity within finite time. Our novel solution to the collision avoidance problem specific to the guidance law is to apply repulsion to the line-of-sight vectors between pairs of agents and intruders. We demonstrate our method's effectiveness with both simulations and a semi-physical experiment.

The experiment results motivate us to consider communication constraints for the subsequent work. Repulsion-based avoidance is unsuitable where other agents' states are obtained via limited communication. We propose instead a significantly modified version of the partition-based velocity obstacle method combined with an event-triggered communication protocol. To limit the scope, we consider the two-dimensional single integrator model and the scenario where agents are tasked with moving to fixed target positions while avoiding collision. Agents are assumed to be connected by a mobile ad hoc network allowing them to communicate with any other agent in the swarm. However, communication for each agent is limited to only one other agent at a time. The protocol determines for each agent when to communicate and to whom and reduces the rate of communication. The method's effectiveness is shown with simulations.

We further extend the work to overcome its limitation on agent numbers and spatial configuration by designing a hybrid collision avoidance method combining the spatial partition-based Voronoi Cell and Velocity Obstacle methods. In addition, to overcome deadlocks and livelocks, we introduce a priority system for distributed coordination by having agent pairs make mutual decisions based on each agent's conditional priority. A similar event trigger-based communication protocol is presented. Our method’s effectiveness is demonstrated in multiple simulations involving up to 100 agents.

Finally, to apply the single integrator collision avoidance methods to the constrained double integrator system, we develop a trajectory buffering method using the input partition-based Barrier Certificate collision avoidance method. We feed a virtual single-integrator agent to the previous hybrid collision avoidance method and use the provided input and position as nominal states to be tracked by the actual UAV. Its relative position then determines the virtual agent’s progress along the nominal input direction. The barrier certificate method is used to ensure that the agent never exceeds a preset distance from the nominal position.

The methods we present in this work are aimed at swarms of quadcopter UAVs and are primarily validated by simulations. Assumptions on the dynamics and communication system are based on literature and current technology. The methods are not necessarily limited to the scenarios discussed and recommendations for future work are discussed.

Publication list

Presented in thesis. Accepted subject to minor revisions

[1] A. H. Zaini and L. Xie, "Distributed Drone Traffic Coordination using Triggered Communication," Unmanned Systems.

Publications presented in thesis

[2] A. H. Zaini and L. Xie, "A Hybrid Collision Avoidance Algorithm for Multi-Agent Traffic Coordination Under Limited Communication," in 2018 15th International Conference on Control, Automation, Robotics and Vision (ICARCV), 2018, pp. 1879-1884.

[3] A. H. Zaini and L. Xie, "Triggered Communication for Reciprocal Collision Avoidance in Multi-agent Navigation," in 2018 14th IEEE International Conference on Control and Automation (ICCA), 2018: IEEE.

[4] B. Zhu, A. H. B. Zaini, and L. Xie, "Distributed guidance for interception by using multiple rotary-wing unmanned aerial vehicles," IEEE Transactions on Industrial Electronics, vol. 64, no. 7, pp. 5648-5656, 2017.

[5] B. Zhu, A. H. B. Zaini, L. Xie, and G. Bi, "Distributed guidance for interception by using multiple rotary-wing unmanned aerial vehicles," in 2016 IEEE International Conference on Advanced Intelligent Mechatronics (AIM), 2016, pp. 1034-1039.

[6] B. Zhu, J. Xu, A. H. B. Zaini, and L. Xie, "A three-dimensional integrated guidance law for rotary UAV interception," in 2016 12th IEEE International Conference on Control and Automation (ICCA), 2016, pp. 726-731: IEEE.

Other UAV related works

[7] T.-M. Nguyen, A. H. Zaini, C. Wang, K. Guo, and L. Xie, "Robust Target-relative Localization with Ultra-Wideband Ranging and Communication," in 2018 IEEE International Conference on Robotics and Automation (ICRA), 2018, pp. 2312-2319: IEEE.

[8] T. Minh Nguyen, A. Hanif Zaini, K. Guo, and L. Xie, "An Ultra-Wideband-based Multi-UAV Localization System in GPS-denied Environments," presented at the International Micro Air Vehicle Conference and Competition 2016, Bejing, China, 2016.

[9] K. Guo et al., "Ultra-wideband-based localization for quadcopter navigation," Unmanned Systems, vol. 4, no. 01, pp. 23-34, 2016.