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Cooperative path planning with applications to target tracking and obstacle avoidance for multi-UAVs

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Abstract: In this paper, we propose a hybrid approach based on the Lyapunov Guidance Vector Field (LGVF) and the Improved Interfered Fluid Dynamical System (IIFDS), to solve the problems of target tracking and obstacle avoidance in three-dimensional cooperative path planning for multiple unmanned aerial vehicles (UAVs). First, LGVF method is improved for UAV cooperative target tracking in 3D environment by introducing vertical component, with two guidance layers containing steering control and speed control. Second, IIFDS method is presented for UAVs to avoid obstacles or threats in complicated environment, where the local minimum problem is well resolved. Moreover, some cooperative strategies are added into the IIFDS framework to satisfy the constraints of obstacle avoidance and cluster maintenance. Finally, the missions of tracking target and avoiding obstacles can be performed simultaneously, by replacing the original sink fluid of IIFDS with the vector field of LGVF. Besides, the reactive parameters of IIFDS can be adjusted by the rolling optimization strategy to enhance the path quality. The experimental results validate the effectiveness of the hybrid method.

Keywords: Lyapunov Guidance Vector Field (LGVF); Improved Interfered Fluid Dynamical System (IIFDS); unmanned aerial vehicles (UAVs); three-dimensional cooperative path planning; the rolling optimization strategy

1 Introduction

In the last few decades, the unmanned aerial vehicles (UAVs) have been widely utilized in military or civilian fields e.g. surveillance, reconnaissance, search and rescue operations. The increasing demands have brought in the focus on enhancing the intelligence and autonomy of UAVs. Autonomous path planning is one of the critical UAV technologies to reduce dependencies on human operators [1-3]. Compared to the simple two-dimensional (2D) path, a three-dimensional (3D) route is more effective in improving UAV capabilities of low-altitude penetration and terrain following. Besides, multiple UAVs can carry out tasks more efficiently than single UAV. The 3D cooperative path planning problem, with applications to target tracking and obstacle avoidance simultaneously in a complicated and dynamic environment, is hence studied in this paper.

Target tracking is a complicated problem involving in multi-sensor information fusion, image processing, control technology, etc. And it is regarded as a path planning problem in this paper, assuming the target motion to be known. If there is only one UAV performing the task of target tracking, the target will flee easily from the field of view (FOV) of camera, which is a small circular region and cannot cover the whole planning space. But team tracking will improve the sensor coverage by sharing information between UAVs. In previous works, many motion planning methods have been proposed for cooperative target tracking. For the collaborative tracking task in urban environments, Shaferman et al. [4] model the restricted region, sensor coverage region and visibility area, and utilize the co-evolution genetic algorithm (CEGA) to optimize the tracking performance of UAVs. In Ref [5], rendezvous and standoff target tracking is solved by using the differential geometry, with the advantages of explicit use of a target velocity, rigorous stability and tuning parameter reduction. The nonlinear model predictive control method with fully decentralized controller structure is presented to get the optimal performance of standoff tracking for multiple UAVs [6]. The dynamic programming method is adopted to minimize the distance error covariance but it ignores the relative angle in Ref [7]. Frew et al. [8] propose the Lyapunov Guidance Vector Field (LGVF) for two-UAV standoff target tracking. In the decoupled guidance structure, heading-rate and speed are controlled respectively for the convergence to standoff distance and uniform phase distribution. To make UAV converge to standoff circle along the shortest route, Chen et al. [9] propose the tangent guidance vector field (TGVF), but this method fails when UAV is inside of the limit cycle. Hence the LGVF and TGVF method are adopted separately when UAV is inside or outside of the expected limit cycle in Ref [10]. Besides, there are other algorithms utilized in this area e.g. the Helmsman behavior, controlled collective motion, backstepping theory, partially observable Markov decision

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