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Unmanned Aerial Vehicle Formation Flying Path Plan by Combined Algorithm of Potential and Lyapunov

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ABSTRACT: This paper discussed and introduced a new path-planning algorithm, based on improved potential field and Lyapunov guidance vector field. According to the requirements of the unmanned aerial vehicle for tracking and obstacle avoidance mission, a real-time method is proposed by combined algorithm of Lyapunov and potential. The features of this newly introduced algorithm are real-time, fast computing and obstacle avoidance capability which causes the algorithm to perform well in complex environments and applications like coordinated tracking of unmanned aerial vehicles. Improved potential flow field primarily provides obstacle avoidance feature and Lyapunov guidance vector field provides tracking feature for this newly introduced algorithm. To achieve the mission of tracking the target and avoid the obstacle at the same time, the guidance vector field by Lyapunov guidance vector field is taken as the original vector field of improved potential flow field. The results prove that the new hybrid and combined method is applicable to complex environments and complex application like coordinate tracking of moving target.

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1- Introduction

Unmanned Aerial Vehicles (UAVs) group performance with the ability to perform spread and low-cost operations is very important. In this paper, the aircraft of the type fixed-wing has been considered. Path planning algorithms can be separated into two types: a. Path planning algorithms based on obstacle avoiding missions. b. Path planning algorithms based on target tracking mission. Stand-off methods are used due to better performance of the Gimbal sensors. In this way, the target range is considered rather than a point. In this method, the UAV finds proficiency on the environment. The Lyapunov vector field method is used in this paper. The optimal UAV speed is obtained at any position of the range of motion and this speed is applied as the optimal speed and optimal angle for low-level control systems to trace the path. In [1], the potential and virtual force field methods have been independently used for path planning in the two-dimensional coordinate. These methods include singular area. In this paper, the modified potential approach [2] is used to solve this problem. This article is based on research conducted in papers [3, 4] on the unmanned vehicles. In the common Lyapunov method, target tracking has been carried out regardless of the obstacles in the environment. In this paper, a new method will be discussed in the target tracking mission, which resolves the defects of Lyapunov vector field method for tracking a moving target, and the target tracking performed in Lyapunov vector field method in the presence of obstacles. In this paper, the new combined Lyapunov vector field algorithm and the modified potential algorithm has been expressed, which the new algorithm removes the weakness of Lyapunov vector field algorithm in the presence of obstacles, and thus, the new algorithm can be used to track the moving targets in the presence of obstacles. Finally, the modeling has been carried out for group flight as well.

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2- Kinematic Model of the UAV

This article assumes that the UAV is equipped with a low-level Flight Control System (FCS) which makes the angles of roll, pitch and Yau stable. with these assumptions, the absolute kinematic model is as follows:

$$\begin{aligned} \dot{x} &= u_1.\cos\psi + W_x \\ \dot{y} &= u_1.\sin\psi + W_y \\ \dot{\psi} &= u_2 \\ \dot{h} &= u_3 \end{aligned} \tag{1}$$

Where, $[x, y, h]^T \in \Re^3$ is the UAV three-dimensional position, $\psi \in [0, 2\pi)$ is the UAV heading angle, $[W_x, W_y]^T \in \Re^2$ is stable wind speed in Cartesian coordinates $u_i\left(m/s\right) \in U_i, i=1,2,3$ is the UAV speed with the following limits

$$\begin{aligned} U_1 &= \left\{u_1 \in \Re \mid 0 \le v_{\min} \le u_1 \le v_{\max}\right\} \\ U_2 &= \left\{u_2 \in \Re \mid \left|u_2\right| \le \omega_{\max}\right\} \\ U_3 &= \left\{u_3 \in \Re \mid \left|u_3\right| \le \dot{h}_{\max}\right\} \end{aligned} \tag{2}$$

The two-dimensional kinematic model of the UAV is used in this paper. If the target is moving at a constant speed of $[x_t, y_t]^T \in \Re^2$ and relative distance to the target is assumed as, the kinematic model of Eq. (1) can be written as:

$$\begin{aligned} \dot{x}_r &= u_1.\cos(\psi) + W_x - \dot{x}_t \\ \dot{y}_r &= u_1.\sin(\psi) + W_y - \dot{y}_t \\ \dot{\psi} &= u_2 \end{aligned} \tag{3}$$

where $[x_r, y_r]^T = [x - x_t, y - y_t]^T$ is the UAV position in the target frame.

3- Improved Potential Flow Field + Lyapunov Vector Field

The main idea and the basis used in combination of these two methods is to substitute the sink field with the Lyapunov vector field. In this case, due to the convergence of Lyapunov method to the loiter circle, as well as benefit from the use of source field for the obstacles, as a result, these two methods, are combined well with each other hence, the weaknesses of the Lyapunov vector field algorithm will be eliminated.

4- Results and Discussion

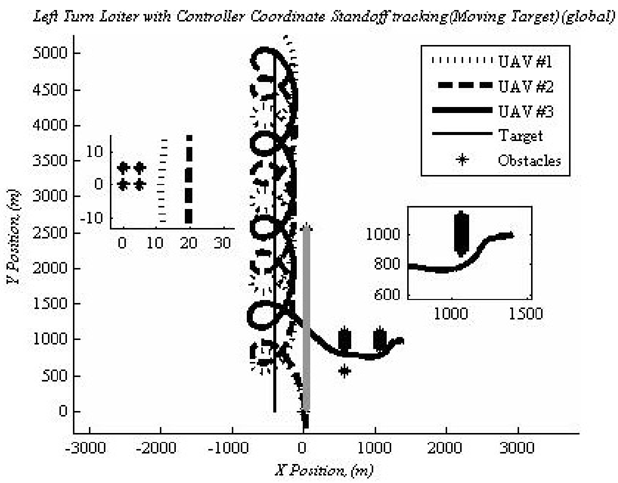

Fig. 1. Application of this newly introduced vector field.

Fig. 1 is obtained by applying the new vector field algorithm with the modified potential algorithm for group flights. The Controller used for a group flight is a control described in the section of cooperative flight for multiple UAVs. The objective is to show the convergence as well as avoiding the obstacle in the combined method. In the above simulation, a UAV began to move from point [1400,1000], another from point [30, -200] and the other from point [30, -300] and obstacles are as two walls like and square shape obstacles in the path of the two lower UAVs (which the above figure has been drawn with greater magnification in the next figure). In addition to the obstacles mentioned above, there is also a square shape obstacle moving at a speed of 5 meters per second in the vertical direction, which is displayed with a continuous line in the figure. In modeling, the maximum angular speed is assumed as 0.2 rad/s, the loiter circle radius as 300 meters, commanded UAV speed is 20 (m/s), and also the target begins to move from point [-400,0] and moves with a constant speed of 10 (m/s) in the direction of +y. Modeling is performed, there is no wind in the background and $K_r = 20, K_v = 0.005, Q_{\sin k} = 20, Q_{source} = 20.4$. Also the optimal relative angle between UAVs is given in 120 degrees. In modeling, the initial velocity of UAVs was in the direction of the field. In the following, the graph showing the convergence to the loiter circle is displayed. Fig. 2 represents the convergence to the loiter circle.

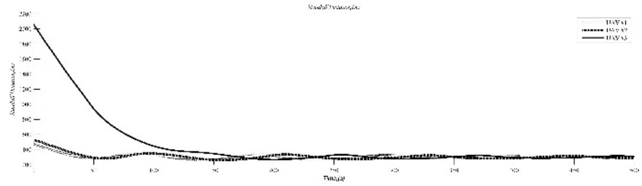

Fig. 2. The distances to the center of loiter circle

As you can see, all UAVs are converging well to the stand-off distance with the combined algorithm. In the following, Fig. 3 is given, showing the angle between the UAVs.

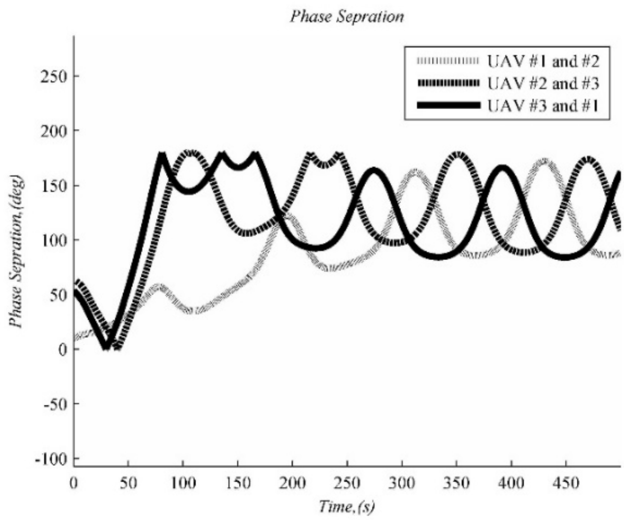

Fig. 3. The Difference of phase angle between the unmanned aerial vehicles

Fig. 3, Demonstration of the differential phase angle between the unmanned aerial vehicles. As can be seen from Fig. 3, after a certain time, the UAVs reach the convergence range and get an angle between 120±20 range; modeling time was 500 seconds.

5- Conclusions

In this article, the modified potential field method was combined with Lyapunov vector field method and in the results section, the team flight mission aimed to track a moving target in the presence of obstacles was given with the newly proposed method as well. the main innovation of this paper is introducing a new approach for target tracking. The new method is able to track a moving target and, has the ability to avoid obstacles and eliminates defects of the Lyapunov vector field method.

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