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Research on the Guidance Law for UAV Rendezvous Based on Virtual Leader

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Research on the Guidance Law for UAV Rendezvous Based on Virtual Leader

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Abstract. The rendezvous of UAVs as a first step in the formation of a UAV is crucial. In this paper, a maneuvering system based on virtual leader is proposed. Firstly, the relative kinematics model of the virtual leader and UAV is established, and then a proportional guidance law with falling angle constraint is designed to make the UAV. Finally, the desired attitude angle can be achieved, and the speed of the UAV can be controlled, so that the UAV can track the virtual leader at a set speed and maintain a relative distance, thereby achieving the purpose of formation flying. The simulation results show that this method can effectively guide the formation of UAVs and has certain engineering application value.

1. Introduction

A single UAV will inevitably be subject to performance limitations during mission execution, such as limited attack range and insufficient reconnaissance capabilities. And the formation of the formation by rendezvous the assembly will make up for these shortcomings of the single UAV, improve the success rate of execution tasks and the ability to resist emergencies [1]. In this context, the research on the issue of UAV formation has become a hot topic, including formation, formation maintenance, formation transformation, formation disbanding and so on [2]. At present, there are many researches on the related issues of UAV formation flight and formation control at home and abroad [3-5], and there are few related studies on formation assembly.

Among these problems in the rendezvous of formations, the focus is on the strategic aspects of assembly [6, 7], and the guidance laws for specific assembly are rarely involved [8, 9]. In the data reviewed by the author, the literature [10] proposes the assembly method of the virtual leader, and discusses its advantages. The rendezvous guidance law designed in [9], although considering only the two-dimensional plane, is based on the visual line guidance law. It is strong and simple to implement. Therefore, based on this, this paper extends it to 3D and proposes the guidance law for the virtual machine to track down the virtual leader. Multiple UAVs can be assembled under the guidance of the same virtual leader, and the virtual leader is adopted. It can avoid the impact of physical long-term problems on the overall formation and improve the success rate of successful formation. The design of the guidance law of this paper also draws on the airborne refueling of drones and the proportional guidance law with falling angle constraints used in missiles [11-13]. The guidance law has the advantages of strong practicability, high accuracy and simple structure, and has certain reference value for the assembly of UAVs.

2. Problem description

Aggregation formation refers to the process in which multiple UAVs arrive at designated areas from different locations and form a certain formation according to requirements. The virtual leader based assembly proposed in this paper is to design a virtual leader for the UAV. The virtual leader flight is scheduled to fly, and each UAV is guided by the virtual leader. At the same time, each UAV is required to maintain a certain relative distance between virtual leader. Therefore, from the perspective of guidance, it is necessary to control the relative position of the UAV and the virtual leader. Firstly, the relative kinematics model of the virtual leader and the UAV is given, and then the design of the guidance law is carried out. Figure 1 and Figure 2 show kinematics analysis of the UAV and the virtual leader.

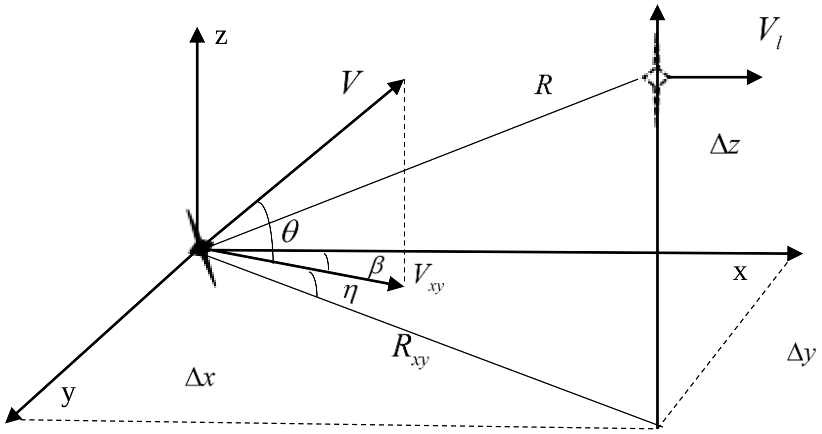

Figure 1. UAV and virtual leader three-dimensional movement

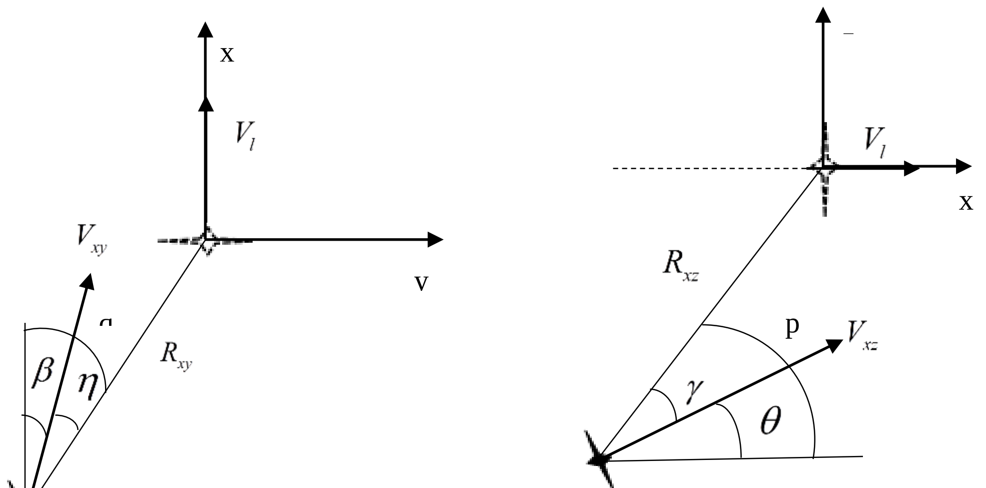

Figure 2. UAV and virtual leader horizontal and vertical movement

It can be seen from Figure 1 that the virtual leader is flying in the $+X$ direction at the speed V_l, the UAV is located behind the virtual leader, the speed is in the direction of the V and coincides with the direction of the heading and the speed in the horizontal plane is V_{xy}; The pitch angle is positive, and the general range is -90°~+90°. At the same time, as shown in Figure 2, γ is the angle between V_{xz} and R_{xz} in the vertical plane, which is called the vertical deviation angle; R is the relative distance between the UAV and the virtual leader. It is projected on the horizontal plane as R_{xy}, and the vertical plane is projected as R_z; β is the heading angle, which is positive in the $+X$ direction and negative on the left side; η is V_{xy} and The angle between R_{xy}, called the line of sight deviation angle, is defined as positive on the right side in the V_{xy} direction and negative on the left side. In Figure 2, p and q are target line angles in the horizontal and vertical directions, respectively.

Therefore, establish the kinematics equation as follows

$$\Delta\dot{x} = V_l - V\cos\theta\cos\beta \tag{1}$$

$$\Delta\dot{y} = -V\cos\theta\sin\beta \tag{2}$$

$$\Delta\dot{z} = -V\sin\theta \tag{3}$$

where $\Delta\dot{x}$, $\Delta\dot{y}$ and $\Delta\dot{z}$ denote the Speed difference of the UAV and the virtual leader along the three-dimensional.

$$q = \arctan\frac{\Delta y}{\Delta x} \tag{4}$$

$$p = \arctan\frac{\Delta z}{R_{xz}} \tag{5}$$

$$\dot{q} = \frac{\Delta\dot{y}\Delta x - \Delta y\Delta\dot{x}}{\Delta x^2 + \Delta y^2} \tag{6}$$

$$\dot{p} = \frac{\Delta\dot{z}R_{xy} + \Delta z\dot{R}_{xy}}{R^2} \tag{7}$$

$$\dot{R}_{xy} = \frac{\left(\Delta\dot{x}\Delta x + \Delta y\Delta\dot{y}\right)}{\sqrt{\Delta x^2 + \Delta y^2}} \tag{8}$$

where $\dot{q}$ and $\dot{p}$ denote the rate of the target line angles in the horizontal and vertical directions along respectively.

3. Guidance law design

The purpose of the guidance law design is to make the horizontal and vertical target line deviation angles between the UAV and the virtual leader reach p_c and q_c respectively, and the relative distance between the UAV and the virtual leader is R_c and the speed is consistent. Therefore, the following guidance laws are designed:

$$\dot{\beta} = k_1\dot{q} + k_2\left(q - q_c\right) \tag{9}$$

The above formula is the horizontal guidance law, where k_1, k_2 are guidance parameters, q_c is the expected horizontal target line deviation angle.

$$\dot{\theta} = k_3\dot{p} + k_4\left(p - p_c\right) \tag{10}$$

The above formula is the vertical guidance law, where k_3, k_4 are guidance parameters, p_c is the expected vertical target line deviation angle.

$$\dot{V} = k_5 (V_l - V) + k_6 (R - R_c) \tag{11}$$

The above formula is speed control law, the controller controls the speed based on the relative distance. , k_5, k_6 are guidance parameters, R_c is the expected distance.

4. Numerical simulations

Based on the space particle model of UAV and virtual leader, this paper simulates the design of the rendezvous guidance law. According to the previously designed guidance law and the established relative kinematics model, the relevant parameters are set and simulated by MATLAB programming.

4.1 Simulation model

The sensor characteristics are neglected, and the UAV flight control system is characterized by a first-order equivalent link. The time constant is 0.1s. The schematic block diagram of the simulation model is shown in Figure 3.

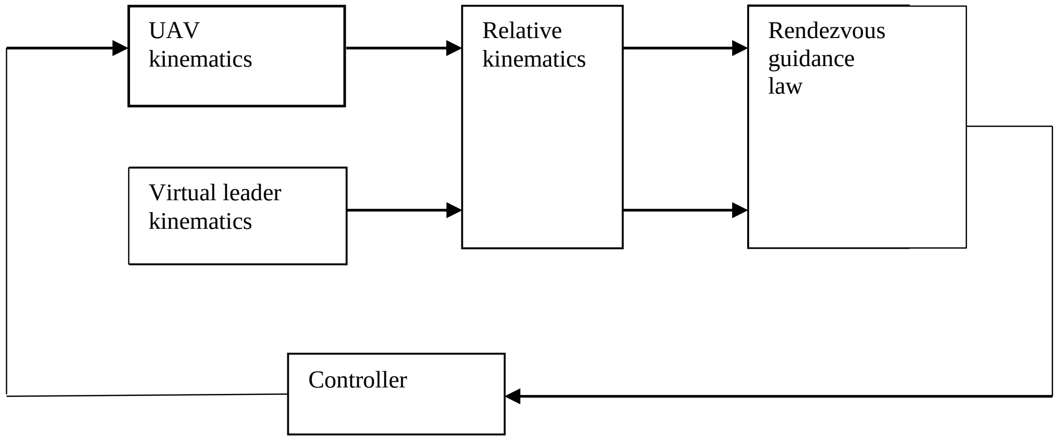

Figure 3. Simulation model structure

4.2 Simulation condition

Suppose there are two UAVs tracking the same virtual leader to form a formation. The initial position of the virtual leader is $(0,0,0)$, the initial speed is $80m/s$, and the initial attitude angle is $(\beta_0, \theta_0) = (0°, 0°)$. The initial position of the UAV 1 is $(-3000, -3000, -3000)m$, and the initial speed is $60m/s$. The initial attitude angle is $(\beta_1, \theta_1) = (40°, 40°)$; the initial position of the UAV 2 is $(-3000, 3000, -3000)m$, the initial speed is $60m/s$, the initial attitude angle is $(\beta_2, \theta_2) = (-40°, 40°)$; the maximum speed and maximum acceleration of the UAV is $150m/s$, $10m/s^2$, and the desired attitude angle of the UAV is $(\beta_c, \theta_c) = (0°, 0°)$, expectation The distance is $R_c = 50m$; the relevant guidance parameter is $k_1 = 0.02$, $k_2 = 0.2$, $k_3 = 0.02$, $k_4 = 0.2$, $k_5 = 0.05$, $k_6 = 0.15$.

4.3 Simulation results and analysis

The rendezvous process of the drone takes two UAVs to track the same virtual leader as an example.

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The attitude angle change, the speed change, and the relative distance change take the UAV 2 as an example. The relevant simulation curves are shown in Figures 4-8.

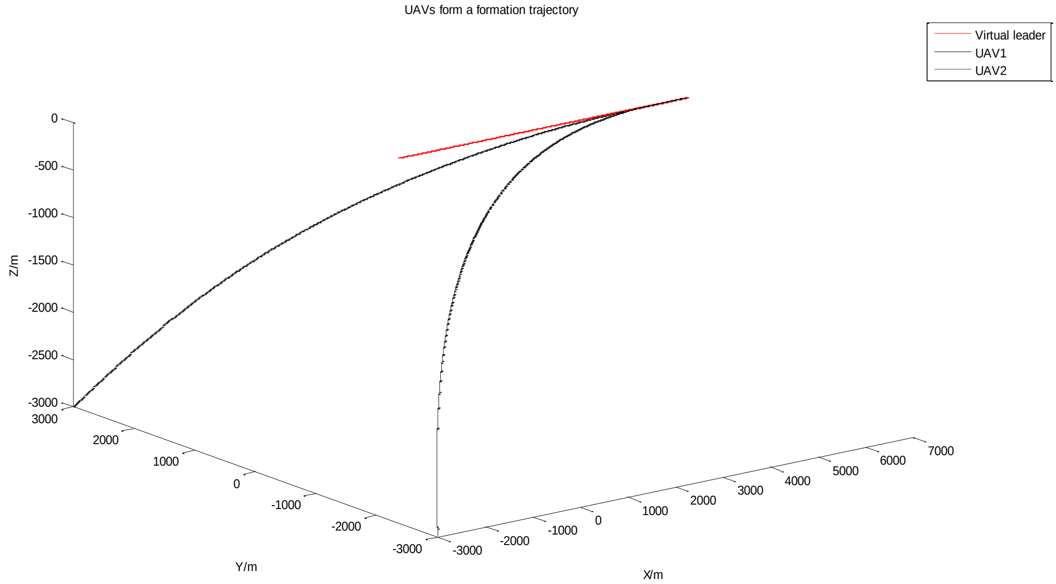

Figure 4. UAVs form a formation trajectory

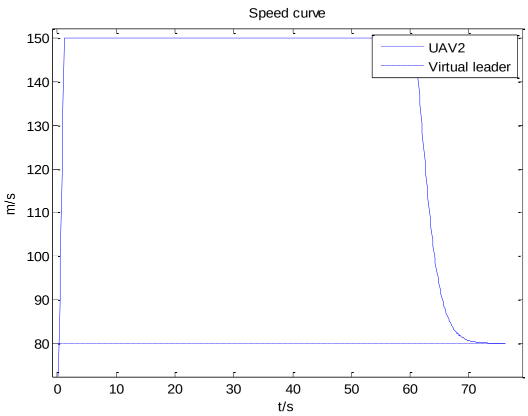

Figure 5. Speed curve

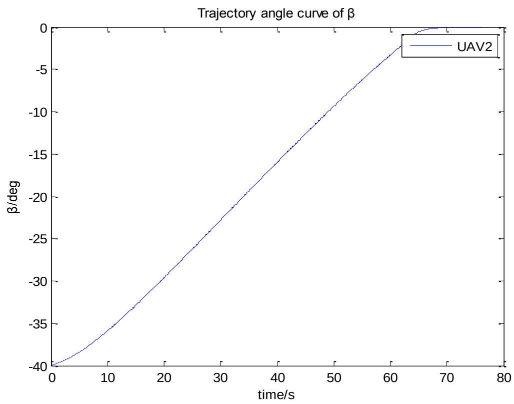

Figure 6. Trajectory angle curve of β

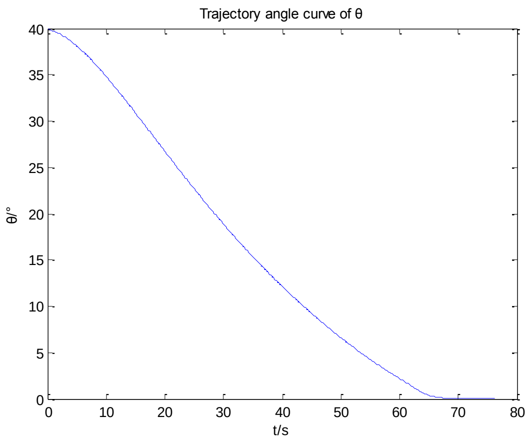

Figure 7. Trajectory angle curve of θ

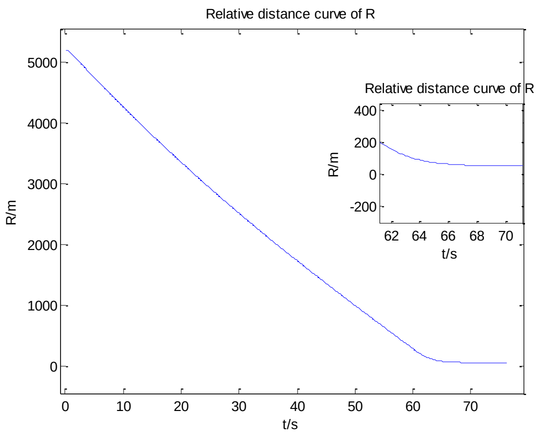

Figure 8. Relative distance curve of R

It can be seen from Figure 4 that the two UAVs form a stable formation under the guidance of the virtual leader, and the relative distance between the UAV and the virtual leader remains stable, and the speed direction is also consistent with the virtual leader, and in the process of forming the formation. The flight path is gentle. As can be seen from Figure 6 and Figure 7, the attitude angle of the UAV 2 finally reaches the desired value and the change is stable without abrupt change. As can be seen from Figure 8, the relative distance between the UAV and the virtual leader reaches the desired value. The above simulation results verify the validity of this guidance law.

The simulation of this paper is based on the spatial particle model. The general guidance law research is based on the particle model, so the research results have certain credibility.

5. Conclusions

Through the research of this paper, the following main conclusions are obtained: Aiming at the guidance problem of formation of multi-UAV, a method of clustering guidance based on virtual leader is proposed. According to the relative motion relationship between UAV and virtual leader, The guidance law is designed. It is verified by simulation that the generated guidance command can better guide the UAV to form a formation and maintain the formation flight, and the form is simple and easy to understand and realize. At the same time, the introduction of virtual leader as a reference point of assembly can replace the real-world long-term assembly method, reduce the risk of accidents caused by real leader, and improve the success rate of assembly. Of course, the above conclusions are based on the simplified model. To be further applied to the project, more in-depth research is needed on a more detailed model.

Acknowledgments

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