COLLISION AVOIDANCE COORDINATE ONLINE-GUIDANCE TECHNOLOGY OF MULTI-UAVS

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Considering the situation that the UAV operates under complex environment, the online-guidance coordinate collision avoidance between the multiple UAVs is studied. Based on the mission importance or the optimal demand on the comprehensive index of each UAV, the velocity change for collision avoidance is assigned proportionally to each UAV. The offset guidance law is applied to the collision avoidance of multi-UAVs, which can guide the relative velocity of UAV to the expected direction before UAV arrive the collision avoidance point. Moreover, numerical simulations are carried out to verify the effectiveness of the method.

Keywords: multi-UAVs; coordinate collision avoidance; online-guidance; offset guidance law

1. Introduction

On the basis of the task distribution result, the UAVs need to attack the target in cooperation and avoid collision in the guidance stage. For the collision avoidance of multi-UAVs, the general solution is that the UAV takes the others as dynamic obstacles, which does not take the cooperation among UAVs into account. There is a difference between the UAV and unknown dynamic obstacle for the UAV can avoid each other.

For the collision avoidance of multiple agents, Erick J. Rodriguez-Seda[1] provide the Lyapunov based cooperate control method for the lagrangian system with multiple agents and obstacles. The integral backstepping method is used, where the navigation function is given when each agent goes forward and the other agent is taken as obstacle, which is prone to generate simultaneous maneuvering.

In paper [2], interval fuzzy kohonen networks algorithm is used to the cooperative avoidance control of the swarm robots. Using stereo vision, multiple moving obstacles avoidance of service robot is studied in paper [3].

In paper [4], speed assignment method is used for conflict resolution in aerial robotics, which finds the feasible speed direction through the search tree. Using differential geometry concepts, Hyo-Sang Shin [5] give the guidance law

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based on velocity obstacle cone, where the sign function is introduced in the control law and the flutter will occur when replanning. In paper [6], through the detection information predicts the obstacle’s velocity and get the envelope line, the conflict is resolved by velocity obstacle method. According to the minimum distance approach method, the reactive obstacle avoidance algorithm is provided in paper [7], which can handle the single obstacle avoidance, while can’t easy to solve the multiple obstacles problem. In paper [8], the selective velocity obstacle method is presented for the coordinate UAV, the encounter plane is devided, the priority and collision avoidance rule is used to determine the collision avoidance strategy. In paper [9], the reciprocal velocity obstacle method is used to settle the multiple agens collision avoidance, which doesn’t consider the path guidance and the dynamic characteristics. In paper [10, 11], the Pythagorean Hodograph (PH) curve trajectory generation method of multiple UAV is given. Through testing the distance on the intersection, justify whether the collision will occer. If collision, increase or decrease curvature. F.Belkhouche [12, 13] adopts kinematic-based navigation laws to settle the robot collision avoidance for the static obstacle, which didn’t analyse the dynamic obstacle avoidance.

In this paper, the reciprocal collision avoidance idea is introduced, considering the dynamic characteristics; the coordinate collision avoidance of multiple UAVs is studied. Based on the mission importance or the optimal demand on the comprehensive index of each UAV, the velocity change for collision avoidance is assigned proportionally to each UAV. The offset guidance law is applied to the collision avoidance of multi-UAVs. The method can achieve the mutual collision avoidance among UAVs without dominant communication and has high computation speed and advantage of real-time, which is suitable for the attack in cooperation of multi-UAV.

2. Collision Judgement

Consider the most severe condition, in which both UAV move forward to each other in space, the relative speed is in their own safety radius, so there is a risk of collision between the UAV, as is shown in Fig. 1.

In Fig. 1, the radius of the UAV A is r_A, the radius of the UAV B is r_B. We can get the UAV A ’s collision cone MBN and the UAV B ’s collision cone OAP by expanding the radius of UAV A and UAV B.

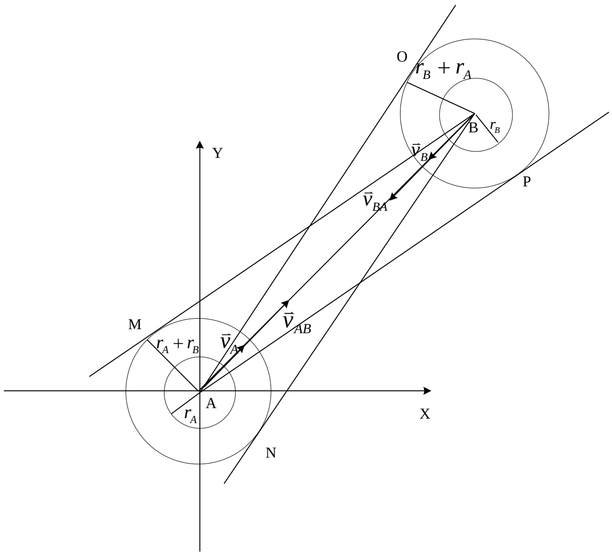

Fig. 1. The schematic diagram of collision judgement between UAV

The speed of UAV A is $\vec{v}_A$, and the speed of UAV B is $\vec{v}_B$,The speed vector $\vec{v}_A$ and $\vec{v}_B$ is on the connecting line between circle center A and B, for both UAVs move forward to each other.

The relative speed of UAV A to UAV B is $\vec{v}_{AB} = \vec{v}_A - \vec{v}_B$, the size of relative speed is v_{AB}, and the direction is $\psi_{v_{AB}}$. The relative speed of UAV B to UAV A is $\vec{v}_{BA}$.

$\vec{v}_{AB}$ is in the collision cone OAP and $\vec{v}_{BA}$ is in the collision cone MBN , there is a risk of collision between UAV A and B, we need take some measure to avoid collision.

The enlarged radius of UAV A and B are both $r_A + r_B$,and the conical angle $\angle MBN = \angle OAP$, and the tangent line AO is parallel to BN , AP is parallel to BM , in other word, $AO \parallel BN$, $AP \parallel BM$.

So even though the UAV A and B are not move forward to each other, as long as $\vec{v}_{AB}$ is in the collision cone OAP , $\vec{v}_{BA}$ must be in the collision cone MBN ,and there is a risk of collision between UAV A and B.

3. Description of collision avoidance strategy

Suppose the speed $\vec{v}_B$ of UAV B keeps unchanged and change the speed $\vec{v}_A$ of UAV A based on the offset navigation laws, then we adjust the relative speed $\vec{v}_{AB}$ to the direction of tangent line AO , correspondingly, the relative speed $\vec{v}_{BA}$ is adjusted to the direction of tangent line BN for $\vec{v}_{AB} \parallel \vec{v}_{BA}$, $AO \parallel BN$ (as is shown in the Figure1).

So there are two conditions when we take measures to avoid collision between UAV:

1) The variation of relative speed is undertook by one UAV, and the path of the other keeps unchanged.

The condition is identical to the collision avoidance of UAV mentioned above, which takes the other as obstacle.

2) The variation of relative speed is undertook by both proportionally.

To the first condition we do not discuss it, and we introduced the second condition emphatically.

To finish the collision avoidance task between UAV, from the view of UAV A ,the relative speed $\vec{v}_{AB}$ need be adjusted to the direction of tangent line AO as $\vec{v}'_{AB}$ under the supposition that the speed $\vec{v}_B$ of UAV B is unchanged. Suppose the size of relative speed $\vec{v}_{AB}$ keeps unchanged, the variation of relative speed $\vec{v}_{AB}$ is $\Delta\vec{v}_{AB}$ ($\Delta\vec{v}_{AB} = \vec{v}'_{AB} - \vec{v}_{AB}$), as is shown in Figure2.

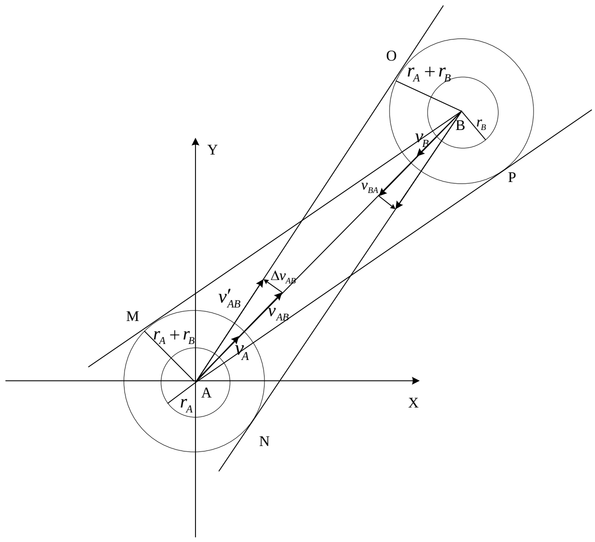

Fig. 2. The schematic diagram of speed adjustment

Suppose the speed variation $\Delta\vec{v}_{AB}$ is undertook by UAV A wholly, and UAV B is taken as obstacle, we can get $\Delta\vec{v}_A = \Delta\vec{v}_{AB}$. So we design the relative speed $\vec{v}_{AB}$ based on the offset navigation laws, select the obstacle point O and get the speed variation $\Delta\vec{v}_{AB}$ real-timely, and we can get the speed variation $\Delta\vec{v}_A$ of UAV A.

If UAV avoids collision in cooperation, the relative speed variation can be distributed into UAV A and B proportionally. Now we select two special conditions to study:

(1) The UAV A and B undertake half of collision avoidance task respectively.

For the UAV A and B undertake half of the collision avoidance task respectively, we know the speed variation of UAV A is $\Delta\vec{v}_A' = \dfrac{\Delta\vec{v}_{AB}}{2}$, the one of UAV B is $\Delta\vec{v}_B' = \dfrac{\Delta\vec{v}_{BA}}{2} = -\dfrac{\Delta\vec{v}_{AB}}{2}$, as is shown in Fig. 3.

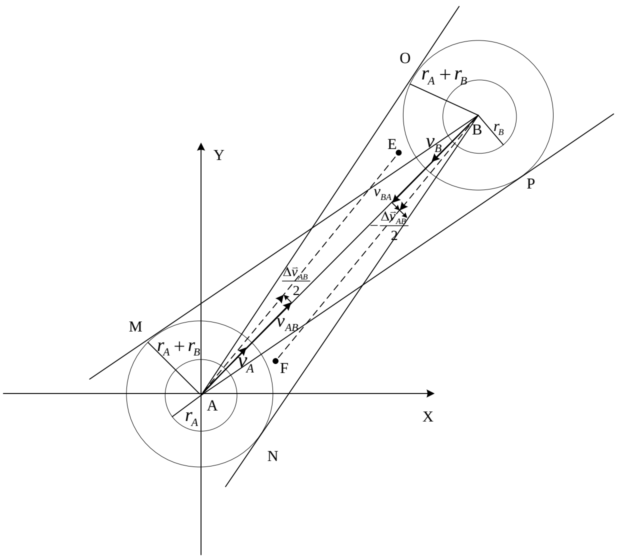

Fig. 3. The schematic diagram of collision avoidance and speed adjustment

To UAV A, the adjusted relative speed $\vec{v}_{ABnew}$ is:

$$\vec{v}_{ABnew} = \vec{v}_{AB} + \Delta\vec{v}_A' = \vec{v}_{AB} + \frac{\Delta\vec{v}_{AB}}{2} \tag{1}$$

Design collision avoidance law, UAV A' keeps the relative speed and arrives at the collision avoidance point E, furthermore, the direction of $\vec{v}_{ABnew}$ is the direction AE.

Establish the motion equation of UAV A' and the collision point based on the Figure3.

$$\dot{r}_{AE} = -v_{AB}\cos\left(\theta_{AE} - \psi_{v_{AB}}\right) \tag{2}$$

$$\dot{\theta}_{AE} r_{AE} = v_{AB}\sin\left(\theta_{AE} - \psi_{v_{AB}}\right) \tag{3}$$

Where r_{AE} is the distance between UAV A' and collision avoidance point E, θ_{AE} is the observation angle of UAV A' to the collision avoidance point E.

Design collision avoidance offset guidance law of $\psi_{v_{AB}}(t)$,

$$\psi_{v_{AB}}(t) = N_1\theta_{AE}(t) + c + b_0 e^{-b_1 t} \tag{4}$$

Determine the range of parameters N_1, b_1 and the value of b_0, c based on the angle of initial point and end point. Suppose the time is t_0 when UAV A find UAV B, and t_{reachE} is the time when UAV A' arrives at collision avoidance point E, so $\psi_{v_{AB}}(t)$ must meet the following conditions:

$$\psi_{v_{AB}}(t_0) = N_1\theta_{AE}(t_0) + c + b_0 \tag{5}$$

$$\psi_{v_{AB}}(t_0 + t_{reachE}) = \theta_{AE}(t_0) = N_1\theta_{AE}(t_0 + t_{reachE}) + c + b_0 e^{-b_1 t_{reachE}} \tag{6}$$

So when UAV A' arrives at collision avoidance point E based on the collision avoidance law, we can get $\psi_{v_{AB}}(t_0 + t_{reachE}) = \theta_{AE}(t_0)$.

Similarly, to UAV B, the new relative speed $\vec{v}_{BAnew}$ is:

$$\vec{v}_{BAnew} = \vec{v}_{BA} + \Delta v'_B = \vec{v}_{BA} - \frac{\Delta v_{AB}}{2} \tag{7}$$

To the Figure3, the collision avoidance point is F in the direction of new relative speed $\vec{v}_{BAnew}$. From the parallel relation, we know the distance between UAV B and collision avoidance point F is equal to the distance between UAV A and collision avoidance point E, both R.

Design collision avoidance law, UAV B' keeps the relative speed and arrives at the collision avoidance point F, furthermore, the direction of $\vec{v}_{BAnew}$ is the direction BF.

Design collision avoidance law of $\psi_{v_{BA}}(t)$,

$$\psi_{v_{BA}}(t) = N_2\theta_{BF}(t) + c' + b'_0 e^{-b'_1 t} \tag{8}$$

Suppose the time is t_0 when UAV B find UAV A, and t_{reachF} is the time when UAV B' arrives at collision avoidance point F, so $\psi_{v_{BA}}(t)$ must meet the following conditions:

$$\psi_{v_{BA}}(t_0) = N_2\theta_{BF}(t_0) + c' + b'_0 \tag{9}$$

$$\psi_{v_{BA}}(t_0 + t_{reachF}) = \theta_{BF}(t_0) = N_2\theta_{BF}(t_0 + t_{reachF}) + c' + b'_0 e^{-b'_1 t_{reachF}} \tag{10}$$

Determine the range of parameters N_2, b'_1 and the value of b'_0, c' based on the t_{reachF} and overload constraint of UAV.

So when UAV B' arrives at collision avoidance point F based on the collision avoidance law, we can get $\psi_{BA}\left(t_0 + t_{reachF}\right) = \theta_{BF}\left(t_0\right)$.

(2) The UAV A undertake $2/3$ of collision avoidance task and UAV B undertake $1/3$ respectively.

From the task assignment of UAV A and B, we can get the variation of $\vec{v}_A$ is $\Delta\vec{v}'_A = \frac{2\Delta\vec{v}_{AB}}{3}$, and the one of $\vec{v}_B$ is $\Delta\vec{v}'_B = \frac{\Delta\vec{v}_{BA}}{3} = -\frac{\Delta\vec{v}_{AB}}{3}$.

To UAV A, based on the(1), (7), the new relative speed $\vec{v}'_{ABnew}$ is:

$$\vec{v}'_{ABnew} = \vec{v}_{AB} + \Delta\vec{v}'_A = \vec{v}_{AB} + \frac{2\Delta\vec{v}_{AB}}{3} \tag{11}$$

To UAV B, the new relative speed $\vec{v}'_{BAnew}$ is:

$$\vec{v}'_{BAnew} = \vec{v}_{BA} + \Delta v'_B = \vec{v}_{BA} - \frac{\Delta v_{AB}}{3} \tag{12}$$

Select collision avoidance point F' in the direction of $\vec{v}'_{BAnew}$, and guide $\vec{v}_{BA}$ to the direction of $\vec{v}'_{BAnew}$ based on the guidance law. So the result is the UAV A undertake $2/3$ of collision avoidance task and UAV B undertake $1/3$ respectively. And furthermore, we can get the movement of UAV A, UAV B.

4. Simulation analyses

Suppose UAV A and B undertake the target attack task in the 2D plane, the initial condition and the target is as shown in the Table1, the shape of the UAV is supposed as circle of radius 1500.

Table1.

The initial condition

	(x, y)	v	ψ	Object Position
UAVA	$(0km, 30km)$	$700\,m/s$	$-\pi/4\,rad$	$(30km, 0km)$
UAVB	$(30km, 30km)$	$700\,m/s$	$5\pi/4\,rad$	$(0km, 0km)$

From calculation, we know there is collision risk near the point $(15km, 15km)$, so need take measure to conduct collision avoidance.

The UAV A and B undertake half of collision avoidance task respectively, the parameters are as follow: $N_1 = 4$, $b_1 = 0.4$, $b_0 = -0.0501rad$, $c = -0.1503rad$, $N_2 = 4$, $b'_1 = 0.4$, $b'_0 = -0.0501rad$, $c' = -9.5751rad$, the simulation result is shown in Fig. 4 to Fig. 9.

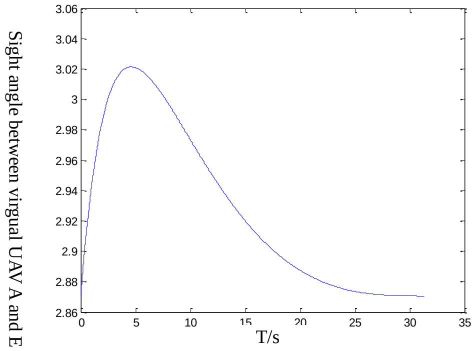

Fig.4. The diagram of sight angle between virtual UAV A and point E

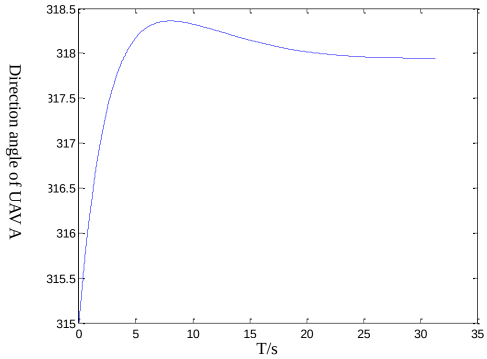

Fig. 5. Diagram of UAV A's direction angle

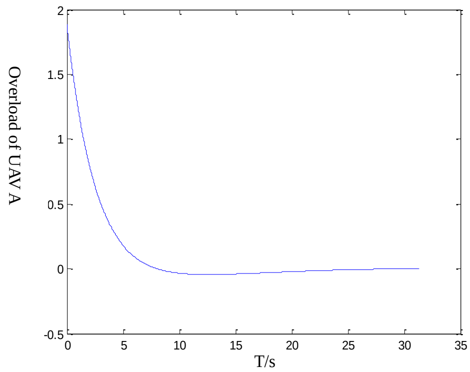

Figure6. The overload of UAV A

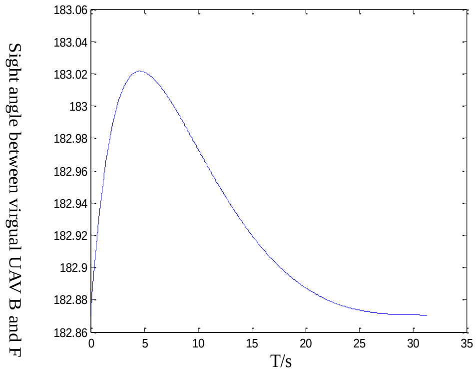

Figure7. The diagram of of sight angle between virtual UAV B and point F

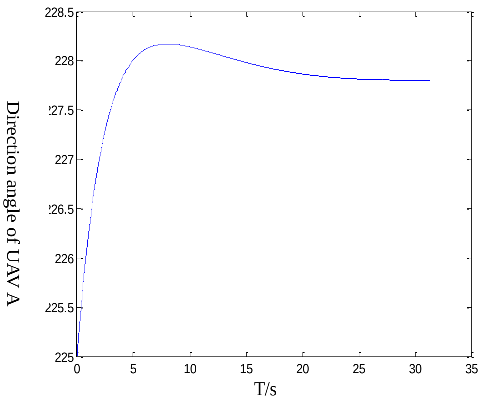

Fig. 8. The diagram of UAV B's direction angle

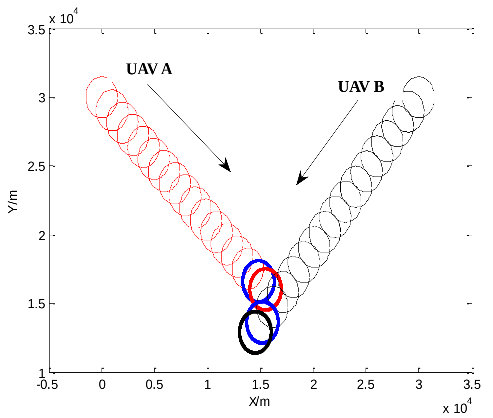

Fig. 9. The diagram of collision avoidance between UAV A and B

From the principle of selection of collision avoidance point E, the time of virtual UAV A to the collision avoidance point E can be gotten.

$$t_{reachE} \geq \frac{27000}{700\sqrt{2}} = 30s$$

And for the UAV A and B undertake half of collision avoidance task respectively, we know the velocity variation of UAV A and B is equal, so the time of virtual UAV B to the collision avoidance point F is $t_{reachF} \geq 30s$. From Figure 4 to Figure 9, we can know when UAV A and UAV B encounter each other, they are tangent to each other, which proves the effectiveness of collision avoidance algorithm. When UAV A and B complete collision avoidance near the point $(15km,15km)$, design liner guidance law to guide UAV to the destination point. The parameters are as follows: $N_{1A}=4$, $b_{1A}=0.4$, $b_{0A}=0.2493rad$, $c_A=$-$16.4934rad$, $N_{2B}=4$, $b'_{1B}=0.4$, $b'_{0B}=0.2808rad$, $c'_B=$-$11.781rad$, the simulation result is shown as Figure10, the UAVs are arrive at each destination point.

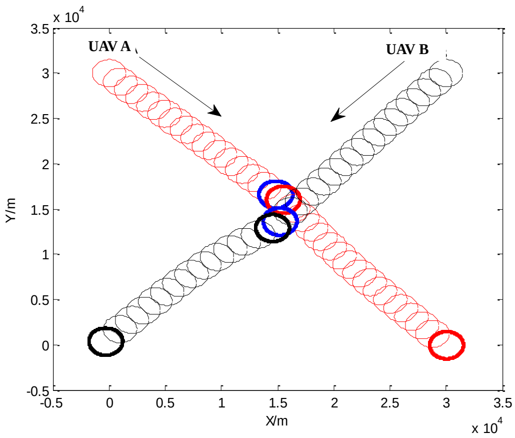

Fig. 10. Collision avoidance between UAV A and B and reach the goal

5 Conclusions

In this paper, the online-guidance coordinate collision avoidance between the multiple UAVs is studied. Based on the mission importance or the optimal demand on the comprehensive index of each UAV, considering the dynamic performance of UAV and completion time constraints, the velocity change for collision avoidance is assigned proportionally to each UAV. The offset guidance law is applied to the collision avoidance of multi-UAVs, which can guide the relative velocity of UAV to the expected direction before UAV arrive the collision avoidance point. Simulation results show the effectiveness of the method. At the same time, the method in this paper can be extended to 3D-plane from 2D-plane. The avoidance algorithm is fit for the online collision avoidance of multi-UAVs. And the next work is to study the online obstacle avoidance in multi-obstacle environment.

Acknowledgements

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