

Real-time flight conflict detection and release based on Multi-Agent system

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Abstract. This paper defines two-aircrafts, multi-aircrafts and fleet conflict mode, sets up space-time conflict reservation on the basis of safety interval and conflict warning time in three-dimension. Detect real-time flight conflicts combined with predicted flight trajectory of other aircrafts in the same airspace, and put forward rescue resolutions for the three modes respectively. When accorded with the flight conflict conditions, determine the conflict situation, and enter the corresponding conflict resolution procedures, so as to avoid the conflict independently, as well as ensure the flight safety of aimed aircraft. Lastly, the correctness of model is verified with numerical simulation comparison.

1. Introduction

At present, flight conflict release algorithms are divided into discrete and continuous types. Carreno [1] proposes a release selection algorithm based on 3D geometry algorithm, which determines the execution after compare all the choices, and evaluate the rationality of the release selection algorithm with simulator. Cheng Liyuan [2] uses Pontryagin minimum principle, the inner point restriction condition and optimal control, to research collision avoidance in plane when control vector in release flight is restricted. Archibald [3-5] introduces the idea of game theory, and proposes a Multi-Agent method to solve the conflict release problem in multi-aircrafts-distributed control. But the discrete release method requires high quality of discretization in calculation, which directly affects the computational complexity and difficulty of the algorithm.

In summary, computation scale of conflict detection and continuous resolution algorithm is large, may not be able to meet the real-time requirements with increasing airspace utilization rate, the possibility of flight conflict may increase as well, so the explore in automation of flight conflict detection and resolution technology is quietly important.

2. Real-time flight conflict detection and release

2.1. Aircraft-agent model

Each aircraft Agent consists of four modules: aircraft information module, flight conflict detection module, negotiation and decision module, decision module, Agent structure.



2.2. Priority of release

The priority of each aircraft is determined by the rescue mission and the stage, meanwhile, we define ①the priority of single aircraft is lower than it of fleet ② consider the fleet size before determine the provisions between two fleet ③judge the priority according to the task and stage when fleet are in the same scale.

The general rules for determining priority are as follows: firstly, the more urgent rescue task is, the higher priority it owns, secondly, go-path is in higher-priority than return-path, lastly, the aircraft with poor maneuverability has higher priority than which with good.

2.3. Conflict release resolution

2.3.1. Nose over. On the basis of visual flight avoiding rules, Agent (J) should yaw to the right, as shown in Figure 1, point P is expected to conflict, when the distance between and P is, etc. vertical safety interval, Agent (J) begins to yaw, TCP2, TCP1, TCP3, TCP4 are track-changed points in the process of liberation. The longitudinal and lateral safety interval are expressed as and , v_i and v_j means the GS of Agent(I), Agent(J), and D_{ij} stands for the distance between two aircrafts when start to release.

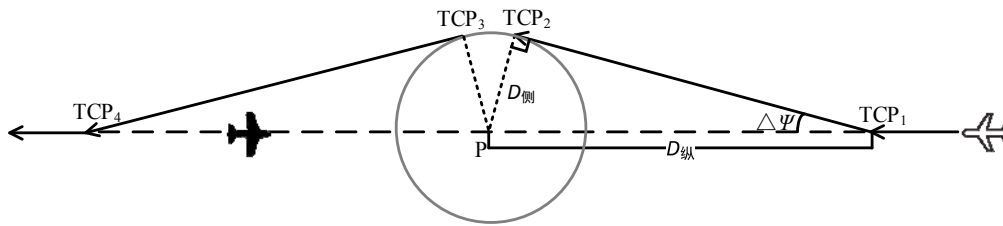


Figure 1. Release track of yaw

TCP1→TCP2: the corresponding release time is t_1 , and the optimal yaw angle set to be $\Delta\Psi$, thus the required interval time from yaw to $D_{\text{侧}}$ is:

$$t = \frac{D_{ij}}{v_i + v_j \cos \Delta\Psi} \quad (1)$$

By the Pythagorean theorem:

$$D_{\text{纵}}^2 = D_{\text{侧}}^2 + \left(\frac{D_{ij} \cdot v_j}{v_i + v_j \cos \Delta\Psi} \right)^2 \quad (2)$$

The optimal release yaw angle is:

$$\Delta\Psi = \cos^{-1} \left(\frac{D_{ij}}{\sqrt{D_{\text{纵}}^2 - D_{\text{侧}}^2}} - \frac{v_i}{v_j} \right) \quad (3)$$

Release track is given out from yaw maneuver trajectory equation.

TCP2→TCP3: the corresponding turning time is t_2 , (x_0, y_0) , (x_2, y_2) , (x_3, y_3) refer to the coordinate of point P, TCP2, TCP3 respectively, according to the law of uniform circular motion:

$$\begin{cases} x_3 = D_{\text{横}} \cos(\psi + \Delta\psi) = x_0 + |x_2 - x_0| \cos \Delta\psi - |y_2 - y_0| \sin \Delta\psi \\ y_3 = D_{\text{横}} \sin(\psi + \Delta\psi) = y_0 + |y_2 - y_0| \cos \Delta\psi + |x_2 - x_0| \sin \Delta\psi \end{cases} \quad (4)$$

(x_t, y_t, z_t) is the coordinate of Agent(J) at time t , and turning rate is ω°/s , the flight track between TCP₂→TCP₃ turns out:

$$p(t_2 + \Delta t) = p(t_2) + \begin{pmatrix} |x_{t_2} - x_0| \cos(\omega \cdot \Delta t) - |y_t - y_0| \sin(\omega \cdot \Delta t) \\ |y_{t_2} - y_0| \cos(\omega \cdot \Delta t) + |x_t - x_0| \sin(\omega \cdot \Delta t) \\ 0 \end{pmatrix} \quad (5)$$

When jaw angle of Agent (J) reaches $2\Delta\psi$, enter to the next flight.

TCP3→TCP4: the corresponding ending time is t_3 , similar to the TCP1→TCP2 trajectory, path of Agent (J) is:

$$p(t_3 + \Delta t) = p(t_3) + \begin{pmatrix} v_j \cdot \sin(\psi - \Delta\psi) \cdot \Delta t \\ v_j \cdot \cos(\psi - \Delta\psi) \cdot \Delta t \\ 0 \end{pmatrix} \quad (6)$$

After flight within t , yaw to right $\Delta\psi$, return to original track, that means the collision has been resolved.

2.3.2. Cross. According to the rules of visual flight avoidance, the aircraft on the left side should climb, and the right one should decrease to avoid flight conflicts. Cross conflict happens as shown in Figure 2, Agent (J) begins to climb when the distance from expected conflict point P is $D_{\text{纵}}$, moreover, TCP1, TCP2, and TCP3 represent the track change points in the release process, H indicates vertical safety intervals.

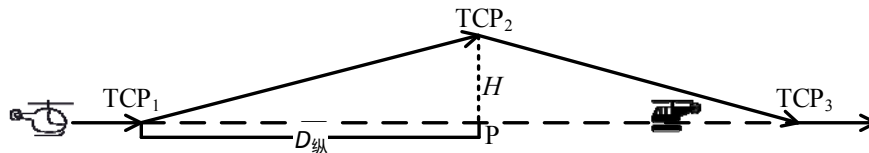


Figure 2. Release track of altitude governing

TCP1→TCP2: $p_1(x_1, y_1, z_1)$ is the coordinate of Agent (J) at TCP1, compute the release time

$$t = \frac{\sqrt{D_{\text{纵}}^2 + H^2}}{v} \quad (7)$$

And release climb rate

$$v_0 = \frac{H}{t} = \frac{Hv}{\sqrt{D_{\text{纵}}^2 + H^2}} \quad (8)$$

TCP2→TCP3: when Agent (J) climb to P at GS v_j , Agent (I) has over the expected conflict point P , Agent (J) can change to the decrease mode and back to the original track. The flight track of TCP2→TCP3 is

$$p(t + \Delta t) = p(t) + \begin{pmatrix} v_j \cdot \sin \psi \cdot \Delta t \\ v_j \cdot \cos \psi \cdot \Delta t \\ -v_0 \cdot \Delta t \end{pmatrix} \quad (9)$$

After the flight time of release, Agent (J) is replaced by flat flight to the original trajectory.

2.3.3. *Catching-up.* According to the visual flight avoidance rule, the Agent (J) should yaw to the right and overtake the front one. As shown in Figure 3, TCP1, TCP2, TCP3, and TCP4 indicate the track change point during the release process.

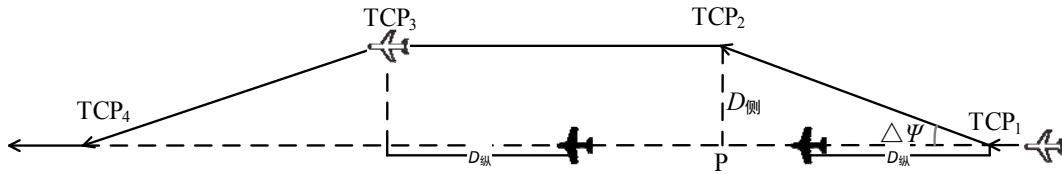


Figure 3. Release track of over fly

TCP1→TCP2: combine the time and angle to complete the leg to get flight trajectory.

$$t = \frac{D_{\text{侧}}}{v_j \sin \Delta \psi} \quad (10)$$

$$\tan \Delta \psi = \frac{D_{\text{侧}}}{D_{\text{纵}} + (v_j \cos \Delta \psi - v_i)t} \quad (11)$$

TCP2→TCP3: Aircraft should over fly Agent (I) while ensure parallel safety interval, and return to the original track until reach the longitudinal safety interval, Set t_2 as the corresponding time for TCP2, thus the motion equation of the track is:

$$p(t_2 + \Delta t) = p(t_2) + \begin{pmatrix} v_j \cdot \sin \psi \cdot \Delta t \\ v_j \cdot \cos \psi \cdot \Delta t \\ 0 \end{pmatrix} \quad (12)$$

TCP3→TCP4: when the distance between aircraft Agent (I) and Agent (J) is satisfied. Set t_3 as the corresponding time for TCP 3, thus the motion equation of the track is:

$$p(t_3 + \Delta t) = p(t_3) + \begin{pmatrix} v_j \cdot \sin(\psi - \Delta\psi) \cdot \Delta t \\ v_j \cdot \cos(\psi - \Delta\psi) \cdot \Delta t \\ 0 \end{pmatrix} \quad (13)$$

2.3.4. Crossing altitude. When two-aircraft conflict happens, and one of them is in level flight, release strategy making is depends on the expected flight track of two aircrafts in geometry; when two aircraft are in the same line, then one of the them should change the original course; when two aircrafts are in the same direction with different speed, the high-speed aircraft is able to over fly the other through course change, when two aircrafts' flight path is expected to cross, lower one should decrease the altitude, and the higher one is expected to uplift the flying height.

When Agent (J) is in the state of climb / descent, the speed need to be governed to realize the conflict release. Set the time window of Agent (I) at the conflict point as $[t_i^{(1)}, t_i^{(2)}]$, and the space distance between Agent (J) and the conflict point is D , thus the time when Agent (j) arrives at the predicted conflict point needs to meet $t_j < t_i^{(1)}$ or $t_j > t_i^{(2)}$. The minimum acceleration required for the crossing earlier than $t_i^{(1)}$ a_1 , the maximum acceleration required for the crossing latter than $t_i^{(2)}$ a_2 , and the initial velocity of Agent (J) v_j , can be obtained by the uniform variable motion law.

$$a_1 = \frac{2[D - v_j(t_i^{(1)} - t)]}{(t_i^{(1)} - t)^2} \quad (14)$$

$$a_2 = \frac{2[D - v_j(t_i^{(2)} - t)]}{(t_i^{(2)} - t)^2} \quad (15)$$

That is, the acceleration a of the Agent (J) needs to be satisfied $a > a_1$ or $a < a_2$, and a_1 , a_2 will be substituted into the governing maneuvering equations, and the trajectories of Agent (J) prior to Agent (I) and after Agent (I) flying over the collision point are obtained respectively

2.3.5. Fleet conflict. There are 8 fleet conflict scenarios, in the scene S_{G1} , S_{G4} , S_{G7} , $\pi_{GAF,DG} > \pi_{GAF,FMCG}$, $\pi_{TAF,TWP} > \pi_{GAF,DG}$, $\pi_{TAF,TWP} > \pi_{GAF,FMCG}$, fleet needed for release in low priority are those executive materials transportation tasks; in the scene S_{G2} , S_{G3} , S_{G5} , S_{G6} , S_{G8} , $\pi_{GAF,DG} > \pi_{GAF,TWP}$, $\pi_{GAF,DG} > \pi_{TAF,TG}$, $\pi_{GAF,FMCG} > \pi_{GAF,TWP}$, $\pi_{GAF,FMCG} > \pi_{TAF,TG}$, $\pi_{TAF,TWP} > \pi_{TAF,TG}$. Low-priority Agent needed to avoid include fleet for the wounded in go-path and for material in return-path. When there is a conflict, there are likely to produce some potential conflict points, and the earliest one will be taken as the expected conflict point. And the strategy of disengagement should be chosen according to the conflict situation of the two aircrafts.

2.3.6. Multi-aircraft conflict. In the case, the Agent involved in the conflict determines their release order according to their respective priority and negotiation. For example, four aircrafts, Agent (H), Agent (I), Agent (J) and Agent (k), have potential conflict in airspace, and the priority is reduced successively, the conflict release resolution:

The highest priority aircraft can maintain the original flight track, others need to compute the release strategy of the aircraft with higher priority than itself, and perform the flight trajectory without conflict ultimately.

3. Simulation

In the aiming rescue airspace, there is a fleet GGAF, DG for material in go-path, GTAF, TG in return-path, ATAF, TWP for the injured in return-path and AIA for disaster reconnaissance. and the priority order of release is GGAF, DG, GTAF, TG, ATAF, TWP, AIA. Ground Speed of GGAF, DG, GTAF, TG, ATAF, TWP, AIA are 50m/s, 40m/s, 55m/s and 70m/s, track angle are 270 degrees and 150 degrees, 80 degrees and 210 degrees. Furthermore, the flight height of GGAF, DG, GTAF, TG, ATAF, TWP is 900 meters, and AIA decreases at 1600 meters with descent rate 10m/s. The initial coordinates are shown in Table 1.

Table 1. Values of initial coordination

Aircraft	Longitude(N)	Latitude(E)	X coordination	Y coordination
$G_{GAF, DG}$	31°43'57.14"	118°51'59.86"	3512259.252	505973.017
$G_{TAF, TG}$	31°46'2.76"	118°48'18"	3516126.774	500132.625
$A_{TAF, TWP}$	31°43'19.82"	118°44'3.96"	3511110.107	493444.483
A_{IA}	31°46'19.43"	118°48'59.76"	3516640.304	501231.461

There are 6 intersections in the flight path of aircrafts $A_{TAF, TWP}$, A_{IA} and fleet $G_{GAF, DG}$, $G_{TAF, TG}$, and form 6 potential conflicts, the coordinates of which are listed in Table 2.

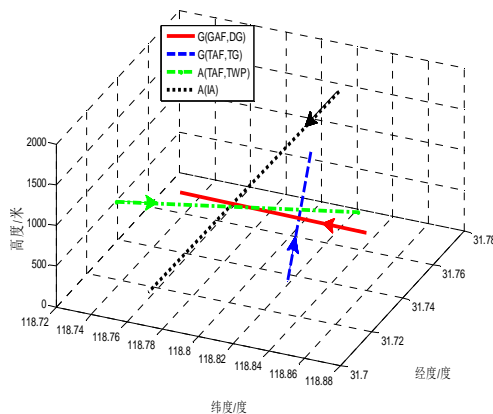
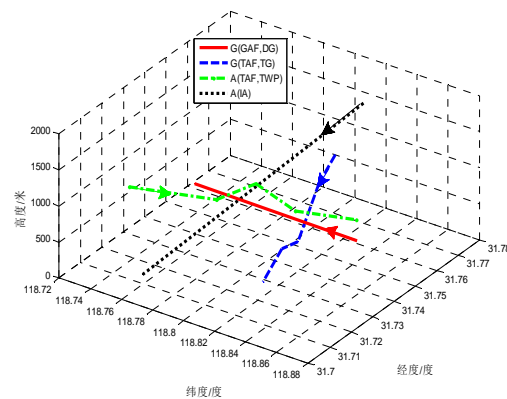
Table 2. Coordination of cross point

Cross point	Longitude and Latitude	XY coordination
1	(31°43'58.95"N, 118°49'41.31"E)	(3512313.536, 502325.752)
2	(31°43'58.91"N, 118°48'3.57"E)	(3512312.045, 499752.815)
3	(31°43'58.98"N, 118°47'24.36"E)	(3512314.277, 498720.639)
4	(31°44'13.46"N, 118°49'31.71"E)	(3512760.407, 502072.949)
5	(31°45'39.26"N, 118°48'33.79"E)	(3515402.957, 500548.171)
6	(31°43'51.69"N, 118°47'19.36"E)	(3512089.754, 498588.987)

After the Agent detected the multi-aircrafts conflict, determine the priority according to the rescue tasks of each aircraft and fleet is $G_{GAF, DG} > G_{TAF, TG} > A_{TAF, TWP} > A_{IA}$, and the order is changed to $G_{GAF, DG}$, $G_{TAF, TG}$, $A_{TAF, TWP}$, A_{IA} after negotiation. The specific release resolutions is shown in Table 3, and the trajectory both of plan and release are shown in following Figures.

Table 3. Resolutions of aircraft

Aircraft	Priority	Resolution
$G_{GAF, DG}$	1	Maintain
$G_{TAF, TG}$	2	Decrease
$A_{TAF, TWP}$	3	Climb
A_{IA}	4	Speed governing

**Figure 4.** Planned trajectory**Figure 5.** Resolution trajectory

4. Conclusion

This paper proposes the conflict detection model based on flight trajectory prediction, and combines protection zone model in basis of standard visual flight interval to compensate special circumstances. According to the release warning time, conflict can be divided into two aircrafts (including fleet) and multi aircrafts. In each mode, different conflict scenarios are divided according to the flight process and the tasks. In the conflict resolution, Multi-Agent system is proposed, each aircraft is regarded as a Agent contains four independent module, and determine the release order based on priority rules, combining with the relative movement to choose altitude, yaw or speed governing of liberation, to perform a conflict release flight trajectory, so as to realize the collaborative flight conflict resolution.

Acknowledgments

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