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Maneuver Strategy in Beyond-Visual-Range Air Combat

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Abstract. In the Beyond Visual Range (BVR) air combat, to occupy a beneficial attacking position is vital in winning of the combat. In this article the fuzzy neural network is adapted to simulate the target's maneuver intension. According to this simulation, a BVR air combat supremacy function model can be set up and it gives suggestions on the maneuver strategy of a one by one basis air combat. Simulate and compare with reality the target's maneuver strategy with or without the back up of the information sources. The simulation results show that the air combat strategic assisting model is valid and it can give effective strategy under different circumstances.

Keywords: BVR Combat, Supremacy Assessment, Intelligent Strategy, Neural Network, Fuzzy Control

1. Introduction

Modern air combat[1] is divided into Beyond Visual-Range (BVR) combat and Within Visual-Range (WVR) combat[2]. BVR combat means the fighters use airborne detection equipment to search the enemy target, then use remote air-to-air missile to attack it, when both of them are beyond visual range[3].

In a BVR air combat, it is not only the detective area of the fire control radar and the attacking distance[4] of a air-to-air missile that limit the attacking, but also the limits of the attacking angle[5] of the fighter. To occupy the vantage point to avoid these limits but leaving the target suffer from these limitations is the key to a victory. Current analysis on the decision strategy is normally based on the evaluation of only the combat situation[6], the threats determination[7] and the target assignment[8], etc. There are only a few works that are based on the aircraft approaching path and the approaching strategy[9]. In this article the target's flight path is predicted by applying the fuzzy neural network, and analyze the aircraft maneuver strategies while ensuring the information sourcing or the situation supremacy respectively.

2. Detection and the Prediction of the Target Maneuver Intention

2.1. Relative Geometric Position

Air combat relative position is shown as in Fig 1.

Define the state vectors C for the attacking aircraft, C^{tgt} for the target aircraft as in .

$C = (x, y, h, v, \gamma, \chi)$, $C^{tgt} = (x^{tgt}, y^{tgt}, h^{tgt}, v^{tgt}, \gamma^{tgt}, \chi^{tgt})$

Amongst these, x, y, h and x^{tgt}, y^{tgt}, h^{tgt} are the position and altitude on the ground coordinates for the attacking aircraft and the target; v, v^{tgt} are the flying speed for the two aircrafts respectively; γ, γ^{tgt} are the flight path angle of declivity; χ, χ^{tgt} are the flight path angle of deflection.

The air combat state vector S can be derived from the relative geometric position of the two aircrafts, and

$$S = (d, d_h, \Delta h, \Phi, q, \theta, v_r) \quad (1)$$

Here d is the distance between the two aircrafts; d_h is the horizontal distance; Δh is the height difference; v_r is the target's relative speed to the attacking aircraft; Φ is the target's advance angle to the attacking aircraft; q is the impact angle (the angle between the target's direction and the target line); θ is the sight angle (the angle between the x axis of the attacking aircraft and the sight line to the target).

2.2. Target Detection Probability of Air-to-Air Missile

The target detection is related to the radar's performance parameters. The key parameters that are affecting this are the maximum searching azimuth φ_R, the maximum searching distance D_R, the detecting probability P_{Rdect}, etc. For a certain RCS target, the radar's detecting probability turns smaller as the distance goes up. When ground air defense system or AWACS has led the aircraft near to the target, which means the target is within the detectable distance of the onboard radar, the detecting probability is

$$P_{Rdect} = (\Phi/360) \times P_{Rfind} \tag{2}$$

Amongst the above, P_{Rfind} is the probability for the radar to find the target. For a target with the RCS at $5m^2$ and at the distance of d, it can be found that:

$$P_{Rfind} = e^{(-0.1625 d/D_R)} \tag{3}$$

Hence under a certain R situation, the probability distribution ΠR of the detectable situation c and the undetectable situation n can be defined as:

$$P(c \mid S) = P_{Rdect},\ P(n \mid S) = 1 - P_{Rdect} \tag{4}$$

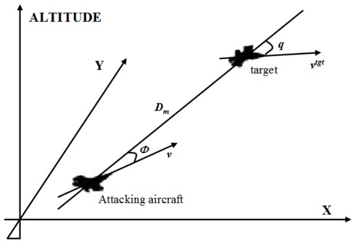


Fig. 1: Relative position for air combat

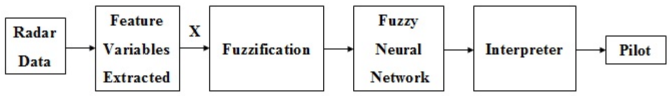


Fig. 2: Target Maneuvering Intension Determination

2.3. Calculating Target Maneuvering Intension

Let the target's dynamic property and the combat situation form a feature space X, the target's maneuvering intension forms an intensional space S. Target Maneuvering is to change the state of the feature space X by finding out the S→X mapping f, and making the aircraft at a dominant position. Calculating theory of the target maneuvering intension is to find out this mapping f. Once f is correctly found, responses for the aircraft maneuvering can be made accordingly.

The approximation of the target maneuvering intension can be made by measurements then calculate the target's velocity, acceleration and the direction, and the knowledge and the experience of an air combat expert. But incorporate the two methods together is more important and vital.

In real air combat, the radar detective area is at the forward hemisphere of the aircraft, assume the combat will take place within the forward hemisphere. Another assumption is that despite the fact that the target has detected the aircraft or not, the target maneuver is all intensional attack maneuvers. Based on the experience of an air combat expert, following 9 maneuvering intensions can be found: (1) Head-on approaching;(2)Left vertical escaping; (3)Side flanking; (4) Same direction escaping; (5)Right vertical escaping; (6)Front side approaching; (7)Front side escaping; (8)Lateral flanking; (9)Rear side flanking.

All the above 9 maneuvering intensions are from the description of the air combat expert. To estimate follow which intension is the target performing, air combat experts have to judge the angular velocity of the target moving against the target line, velocity and direction of the target, together with the knowledge and experience from previous combats. The relations between the target's dynamic property and its maneuvering intension are often uncertain. This is from the uncertainty in the conception and the interrelationship of the target's dynamic property and its maneuvering intension. For the same target maneuvering intension, judges can be ambiguous based on each pilot, and the different judges have no definite limits. Therefore, incorporate the judgments and the calculations for the target maneuvering intensions.

The judgment and calculation of the target maneuvering intension is realized as shown in the Diagram below, and it consists of the dynamic property variables extracted module (including the data fusion), the fuzzification module, the fuzzy neural network reasoning module, and the results explaining module.

Input the target's movement parameters obtained from the fire control radar, the flight control system and the guided system into the system shown in fig 2. The key target property variables are the target impact angle q, target azimuth Φ, distance to the target D_m and the maneuvering angular velocity ω_n of the target moving against the target line. Fig 2 represents the geometric meaning of these variables.

3. BVR Combat Strategy

3.1. Supremacy Function

Decision making needs to evaluate the supremacy and then find out respective benefits of each type of the maneuver strategies. The aircraft supremacy state membership function is obtained by defining the relative state variables: T_d is the distance supremacy, T_Φ is the azimuth supremacy, T_q is the impact angle supremacy, and T_E is the energy supremacy.

Distance Supremacy

The killing probability of a missile to its target is larger when the missile is at a medium launching distance, and when it is near to the nearest or the farthest launching distance, the killing probability is smaller and changes rapidly. When launching within the unescapable area, no matter how the target tries to avoid the attack it can not escape. A distance supremacy function can be derived based on this.

$$T_d = \begin{cases} 0, d \geq D_R \\ 0.5e^{-\frac{d-D_{Mk\max}}{D_R-D_{M\max}}}, D_{M\max} \leq r \leq D_R \\ 2^{-\frac{d-D_{M\max}}{D_{M\max}-D_{Mk\max}}}, D_{Mk\max} \leq r \leq D_{M\max} \\ 1, D_{Mk\min} \leq r \leq D_{Mk\max} \\ 2^{-\frac{d-D_{Mk\min}}{10-D_{Mk\min}}}, 10 \leq r \leq D_{Mk\min} \end{cases} \tag{5}$$

Azimuth Supremacy

When the missile is launched for attacking and it has a significant supremacy to the target, the aircraft has to keep a certain azimuth with the target in order to minimize the threat from the target. Meanwhile, the aircraft has to keep the guidance to the missile to ensure the target is within the detective area. The attacking condition is retained to perform the attack when necessary. The azimuth supremacy function under this circumstance can be defined as:

$$T_\phi^* = \begin{cases} 0, |\phi| > \varphi_R \\ 1 - \frac{|\phi| - \varphi_M}{\varphi_R - \varphi_M}, \varphi_M \leq |\phi| \leq \varphi_R \\ \frac{|\phi|}{\varphi_M}, 0 \leq |\phi| < \varphi_M \end{cases} \tag{6}$$

Impact Angle Supremacy

The effect of the impact angle to the supremacy function is reflected in its effect on the missile killing probability. The simulation results show that when the target is moving a rectilinear motion, the value of the killing probability is symmetrically distributed within the attacking area. The impact angle supremacy function can be defined:

$$T_q = \begin{cases} \frac{|q|}{50}, |q| < 50^\circ \\ 1 - \frac{|q| - 50}{130}, 50^\circ \leq |q| < 180^\circ \end{cases} \tag{7}$$

Energy Supremacy

In order to obtain a larger initial kinetic energy to extend the missile's launching distance, the carrier should increase its speed hence its kinetic energy before launching. To maximize the supremacy the carrier can normally achieves the velocity of sound before launching of the missile. The energy supremacy function can be defined as:

$$T_e = \frac{Eg - Eg^{tgt}}{Eg} \quad Eg = h + \frac{v^2}{2g} \tag{8}$$

3.2. The Rule for Choosing the Decision Strategy

The decision strategy can be chosen by the effectiveness obtained from different decisions.

For a maneuver strategy i, all supremacy functions T_{di}, $T_{\Phi i}$, T_{qi}, T_{ei} can be calculated, therefore by (9) the supremacy function for strategy i is:

$$E = \alpha_s(\beta_d T_d + \beta_\phi T_\phi + \beta_q T_q) + \alpha_e T_e \tag{9}$$

In the above function, α_s, α_e are the weights for the position supremacy and energy supremacy and $\alpha_s + \alpha_e = 1$; β_d, β_Φ, β_q are the distance supremacy, azimuth supremacy, and the impact angle supremacy of the position supremacy respectively and satisfying $\beta_d + \beta_\Phi + \beta_q = 1$.

The determination of the weight value represents the importance of a certain situation. Different weight value can be adapted according to the combat situation to reflect the change in a nominated parameter:

1) To ensure the information sourcing. To make sure the target enters the radar detective area and hence finds out the requirements for the target to enter into the attacking supremacy area. The focused parameters are the distance to the target d, and the azimuth Φ;

2) To ensure the supremacy. To maximize the occurrences of the supremacy in the launching conditions over the target, the attacking aircraft should increase the position supremacy as well as the energy supremacy. As in the BVR (Beyond Visual Range) air combat, azimuth and distance supremacy has fewer effects to the long range air-to-air missile. Increase the weight of the impact angle β_q due to that by adjusting the supremacy area, a supremacy range of a 50° impact angle to the target at the time of launching can be formed.

Detailed realization of the aircraft's maneuver strategy in BVR combat is shown in Fig 3.

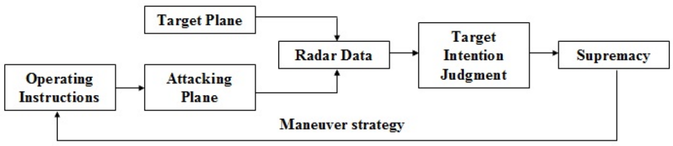


Fig. 3: BVR Combat Maneuver Strategy Model

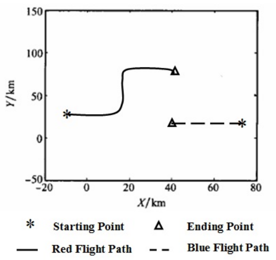


Fig.4 simulation example 1

4. Experiments

4.1. Intention Judgment

Example1: The initial flight state of the red and blue aircrafts is shown in Fig 4. In this simulation, the target follows the conventional air combat tactic that is to avoid a head-on direction attack. The target takes 90°significant move to avoid the radar detection, then have a parallel approaching when it is in the front area, and at a suitable position it performs a front approaching. This is shown in the Diagram below:

The Red's maneuver action obtained from the fuzzy neural network can be divided into 5 phases. At the first phase the target is moving a rectilinear motion. During the second phase the target turns to the left significantly. The target is moving rectilinear during the third phase. While in the fourth phase the target turns to the right hugely. The fifth phase is when the target turns right slightly and gives a judgment on its intension as a front approaching.

The results show that the actual Red flight path is identical to the one obtained from simulation.

4.2. Maneuver Strategy

In this article two types of the flight conditions of the Red and Blue aircrafts are discussed. The maneuver strategy for the Blue aircraft can be derived once the Red flight conditions are predicted.

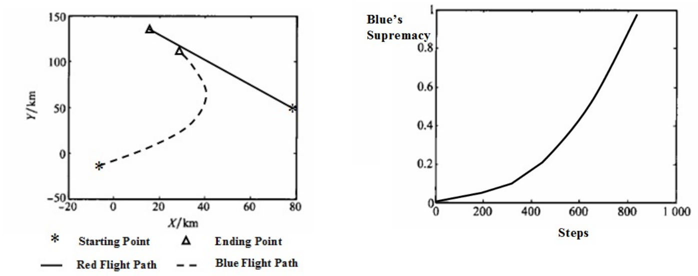
Example 2 The Red can not obtain the air combat situation effectively and it keeps moving a rectilinear line to the initial flight path. The maneuver strategy for the Blue is to get to the rear flank of the Red hence obtaining the advantaged attacking area.

Example 3 The Red can obtain the air combat situation effectively with the assistance of other information sources. It can make tactical decisions to the Blue maneuver strategy. The Blue should try to avoid its exposure to the Red detection and get to the rear flank of the Red aircraft as soon as possible.

Tab 1 is the initial condition for the above two simulation examples.

Tab.1 initial condition

	Blue		Red(target)	
	position/km	attitude angle/(º)	position/km	attitude angle/(º)
Exp. 2	(-9.8,-9.3)	(44,0)	(77.9,55.1)	(124,0)
Exp. 3	(-19.2,6.4)	(89,0)	(86.4,54.2)	(78,0)



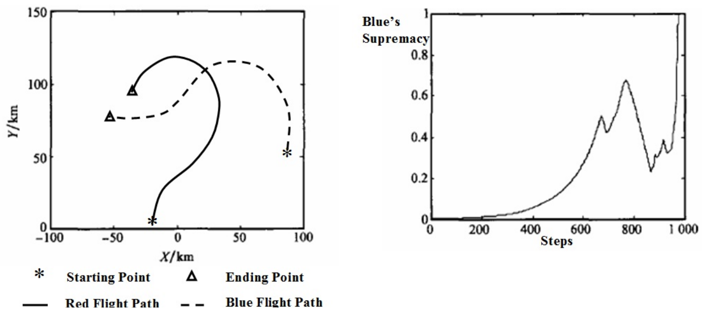
(a) Blue and Red's trajectory (b) Blue's Supremacy

Fig.5 Results of Example 2

The Fig 5 shows the simulation results for the Example 2. There are two phases in the diagram:

1) Information sourcing is ensured (when the simulation started). In order to obtain the information more quickly, the Blue aircraft changes its direction to the Red rapidly, increase the relative speed and get the Red falling into its radar detection area.

2) Ensuring the supremacy (80s during the simulation time). By the definition of the supremacy function, the controlling order from the decision reasoning will lead the combat situation to satisfy Φ =0°, q =50° and to decrease the target distance. tail chasing and coaxial launching tactic Blue takes a series of the roll over to ensure the detection of the Red, but also to increase the Red's azimuth to the Blue, shorten the Red's launching distance, hence decrease its threats. In order to achieve a better launching supremacy, Blue climbs vertically and gain the energy supremacy for the missile once it arrives into the attacking area.



(a) Blue and Red's trajectory (b) Blue's Supremacy

Fig6 Results of Example 3

The Fig 6 shows the simulation results for the Example 3 . Although the Red aircraft made the escape, as the Red flight path is predicted prior to the combat, the Blue aircraft can enters the rear flank area rapidly and get ready to attack.

From the Fig 6, it is clearly that the overall procedure can be divided into the information ensuring phase and the supremacy ensuring phase. Example 3 combat is more complicated than the previous one. From the simulation results, it can be seen that when the target's flight path is predicted, the Blue aircraft can move quickly to the rear flank of the Red and keeps its supremacy while the Red cannot achieve the attacking condition. The method is effective and useful in the analysis of the air combat place occupying.

5. Conclusions

By considering the radar detective probability, used the fuzzy neural network to simulate the target's flight path and its maneuver intension. Applied the condition parameters to analyze the changes in conditions for both the attacking aircraft and the target in the BVR air combat. An aided decision making model was made for the aircraft's maneuver action while ensured the information sourcing and the supremacy over the target. The simulation results show that the model is valid. To apply the result into a multi aircraft BVR combat will be the major issue for the future researches.

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