Research on Fuzzy Guidance Law for Unmanned Aerial Vehicle*

Hui Wang, Zuoyu Guan, Lijun Yu, Bobo Zhang

College of Automation, Harbin Engineering University, Harbin, China

wangh@hrbeu.edu.cn

Abstract - The UAV guidance in combating airspace need to make UAV close to the target and complete air strikes, which need to receive all necessary data and information and use these parameters to achieve the UAV guidance. For processing the problems that are irregular and complex, this paper presents a new guidance law based on fuzzy logic, and use the classic navigation laws such as proportional navigation, that can be successfully used for modeling offensive maneuver in an special case of air-to-air combat encounters. Then the simulation be conducted combined with the actual data.

Index Terms - Fuzzy Control, Combat Maneuver, Proportional navigation.

I . Introduction

To modem fighters, being fast and correct in making decisions is the most important appraisal of decision-making system. Due to the airspace's complexity, data and information which decision-making system depended on are time-varying and uncertainty. So artificial intelligence algorithms will be used to solve this problem. There is a simple situation as shown in Fig1.

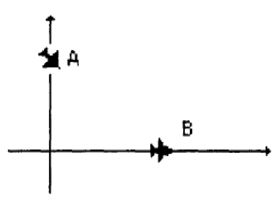

Fig. 1 An encounter situation

Assumed that both fighters have constant speed(Va and Vb respectively) and fighter B moves in the positive direction of x-axis and maintains its direction during the combat. Both fighters have turn radius limitations so that the heading angle of the fighters cannot be freely changed. Now, the problem is to find a maneuver for fighter A to place itself in the back of fighter B suitably. Some severe restrictions on heading are imposed, such as distance, LOS rate and so on. There are many algorithms to design the UAV air combat track guidance system. Wei Ruixuan, Professor of Air Force Engineering University, presented a guidance low based on photoelectric platform, which based on photoelectric platform, making the use of images to choose the target. These images are from UAV ground station transmitted by airborne photoelectric platform. From Beijing University of Aeronautics and Astronautics UAV, Wang Xingdan designs a control system, which makes combination of the proportional navigation and tracking method guidance, and depends on the distance of UAV guidance, but poor intelligence. Cooperated with Northwestern Polytechnical University's Professor Yu Lei, Li Yanjun, Air Force Engineering University's Professor, has designed a guidance algorithm based on pure mathematical theory, and with the idea of optimal control theory. It has high guiding accuracy, but because of the airspace's complexity, the real-time nature of this algorithm is poor. According to this point, a decision-making system based on fuzzy control is presented in this paper.

II . Mathematical Modeling

Considering UAV as a motion of the particle, as shown in Fig 2 is the kinematic relationship between UAV and the target.

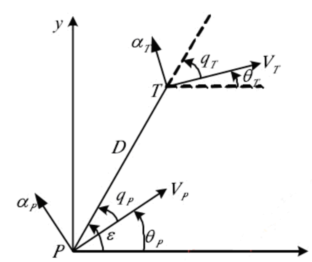

Fig. 2 Two-dimensional motion model

Projecting the speed of V_T and V_p onto the target line of PT and its normal line then:

$$\begin{aligned} \dot{D} &= V_T\cos(\varepsilon-\theta_T)-V_P\cos(\varepsilon-\theta_P) \\ \dot{\varepsilon} &= V_P\sin(\varepsilon-\theta_P)-V_T\sin(\varepsilon-\theta_T)/D \end{aligned} \quad (1)$$

The real-time location of UAV and target can be received by the following formula:

$$\begin{cases} \dot{x}_T = V_T\cos\theta_T & \dot{y}_T = V_T\sin\theta_T \\ \dot{x}_P = V_P\cos\theta_P & \dot{y}_P = V_P\sin\theta_P \end{cases} \quad (2)$$

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As to control Theory, UAV guidance problem can be regarded as a negative feedback process, according to the state of relative motion between UAV and target, the guide track can be determined by controlling the direction of flight.

Ultimately, the best results of successful guidance is to reach the best range of airborne weapons, as shown in equation (3).

$$D(t_f) \le R \tag{3}$$

During the process of navigation, the aircraft maneuver is controlled by the normal acceleration. It needs to meet two conditions for UAV to track the target successfully: 1) The speed of UAV is greater than the target's. 2) The UAV have a stronger mobility than the target.

Tracing method and proportional navigation method are the classic guidance for aircrafts. These two methods' earliest application is in missile seeker technically. Relatively, tracing method can achieve the effect of a good job, but it is strict with turn rate for the aircraft. This paper studies the problem of long-range guidance. The UAV needs to close to the target from the back of the goal. Therefore, using the proportional navigation guidance law has little requirements for turn rate, and combines with fuzzy control to achieve the UAV guidance.

III . Design of Proportional Navigation Fuzzy Controller

Fuzzy control, which is an intelligent algorithm that based on fuzzy set theory, the language of fuzzy variables and fuzzy logic reasoning.

Fuzzy control principles are applied to the UAV guidance, first of all, it needs to determine the input variables of fuzzy controller and output volumes, as shown in Figure 3.4. According to the principle of proportional navigation, make the relative velocity of UAV and target V_R, and LOS rate $\dot{q}$ as fuzzy control input, the normal acceleration n_a (UAV control commands) is output. As shown in the Fig.3 is the schematic.

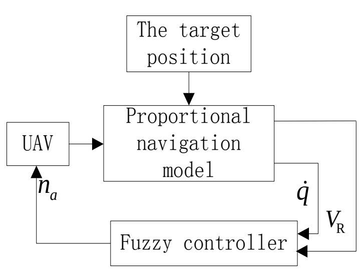

Fig. 3 Fuzzy Control guiding principle

A. Fuzzy variables of proportional navigation

Making the variables of V_R, $\dot{q}$, n_a to domain transformation, it is assumed that the input and output domain of [-6, +6]. Specific process is as follows:

$$V_{RN} = \frac{V_{RN\min} + V_{RN\max}}{2} + k \cdot \left(V_R - \frac{V_{R\min} + V_{R\max}}{2}\right) \tag{4}$$

In the formula, $k = \frac{V_{RN\max} - V_{RN\min}}{V_{R\max} - V_{R\min}}$ is proportional factor.

$V_{R\min} = -|V_T + V|$, $V_{\max} = |V_T + V|$, $V_{RN\min} = -6$, $V_{RN\max} = 6$.

Utilizing the Triangular membership function to convert V_{Rn} to fuzzy variable, the fuzzy subset is divided into seven grades, NB, NM, NS, ZE, PS, PM, PB.

B. The UAV Guidance Control Rules

This section of fuzzy control rule base is based on the logical relationship between the input and output of the navigation, depending on the knowledge and experience of air combat experts. As shown in TABLE1 is the fuzzy controller rules.

TABLE 1 Fuzzy Logic Control Guidance control rule table

$\dot{q}$ n_a V_R	PB	PM	PS	ZE	NS	NM	NB
NB	PB	NB	NM	NS	ZE	PS	PM
NM	PM	NM	NM	NS	ZE	PS	PM
NS	PM	NM	NS	NS	ZE	PS	PS
ZE	ZE	ZE	ZE	ZE	ZE	ZE	ZE
PS	NM	PM	PS	PS	ZE	NS	NS
PM	NM	PM	PM	PS	NS	NS	NM
PB	NB	PB	PM	PS	NS	NS	NM

The meaning of rule base is when the two input variables take a value, there is a corresponding value.

C. The Defuzzification of Control Variables

The results from inference is still a fuzzy vector , which can not be directly used as the control amount, so it must be defuzzied. The method of linear transformation is still used, which is shown in the following formula:

$$n_a = \frac{n_{a\max} + n_{a\min}}{2} + k\left(n_{aN} - \frac{n_{aN\max} + n_{aN\min}}{2}\right) \tag{5}$$

This article is the use of turn rate indicating the aircraft centroid kinetic equation:

$$\begin{cases} \dfrac{dv}{dt} = g\left(n_x - \sin\theta\right) \\ \dfrac{d\theta}{dt} = \dfrac{g}{v}\left(n_a \cos\gamma_s - \cos\theta\right) \\ \dfrac{d\Psi_s}{dt} = \dfrac{g}{v\cos\theta} n_a \sin\gamma_s \end{cases} \tag{6}$$

This article assumes that the UAV flight altitude and speed unchanged, so $\theta = 0$, and UAV lifting force is equal with gravity. The relationship between roll angle of speed and normal turns rate:

$$n_a = \frac{L}{W} = \frac{L}{L \cdot \cos\gamma_s} = \frac{1}{\cos\gamma_s} \tag{7}$$

From the formula above, the change of yaw angle in each sampling time can be obtained, which can simulate the UAV flight path.

IV. Simulation

The known conditions for simulation: the speed of the target: $V_t = 400m/s$, the angle between the horizontal reference line and the direction of target's speed, is a constant: $B_t = 20° = pi/9$ rad , UAV velocity magnitude $V = 800m/s$, the angle between the horizontal reference line and the direction of UAV's speed is constantly changing, and the initial value is $\theta = 0° = 0rad$,the angle between the horizontal reference line and the connection of UAV and target ,is a variable, and the initial value is $q = 0° = 0rad$, the distance between UAV and target, and the initial value is $\mathrm{R} = 10\mathrm{k}m$, the following are the simulation results:

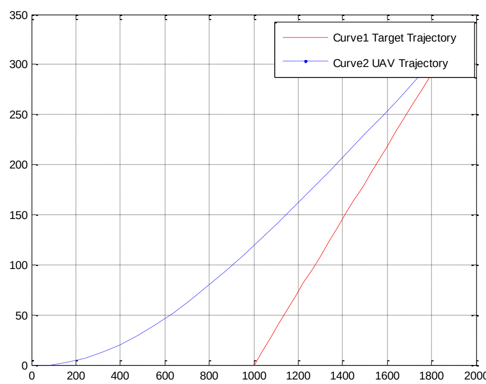

Fig .4 UAV and target trajectory

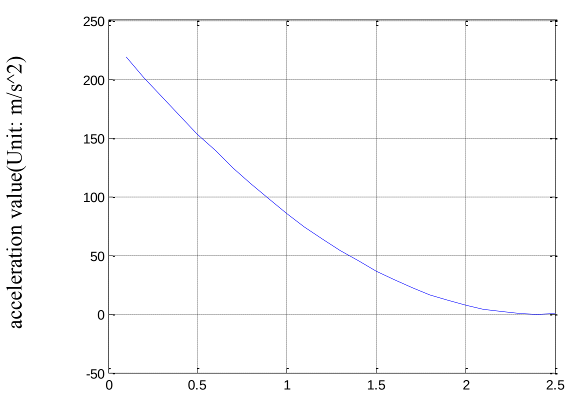

Fig. 5 UAV curve acceleration change

The simulations have been performed to show the applicability of the proposed fuzzy guidance law to combat situations. From the Figure 4, it can be seen that, control guidance system based on fuzzy can achieve a good UAV track that strikes the target. Furthermore figure 5 has shown that the ability of the proposed guidance law to generate satisfactory results with a small turn rate, and in order to accomplish in technology.

V. Conclusion

The paper showed that fuzzy guidance laws with the form of fuzzy rule bases can be successfully used for modeling very complicated air combat maneuvers. Research the classic guidance law, proportional navigation, regarded UAV as carrier aircraft to establish the airspace mathematical model. A controller is designed that combined proportional navigation and fuzzy theory, including the choice of variables, the determination of the membership function and fuzzy rules for the setting. The simulation results show that fuzzy guided method can make the guidance for UAV to reach the target area successfully and with a short time during whole procedure of navigation. The result has confirmed the truth that the system designed in this paper is efficacious.

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