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Fuzzy Predictive Pursuit Guidance in the Homing Missiles

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***Abstract*—**A fuzzy predictive pursuit guidance is proposed as an alternative to the conventional methods. The purpose of this scheme is to obtain a stable and fast guidance. The noise effects must be reduced in homing missile guidance to get an accurate control. An aerodynamic missile model is simulated first and a fuzzy predictive pursuit control algorithm is applied to reduce the noise effects. The performance of this algorithm is compared with the performance of the classical proportional derivative control. Stability analysis of the proposed guidance method is performed and compared with the stability properties of other guidance methods. Simulation results show that the proposed method provides the satisfying performance.

***Keywords*—**Fuzzy, noise effect, predictive, pursuit.

I. INTRODUCTION

GUIDANCE laws of homing missiles are studied within the two basic methods: Pursuit guidance (PG) and the proportional navigation guidance (PNG). The second one has different versions in applications [1, 2]. PG, guides the missile to the current position of the target whereas PNG orientates it to an estimated interception point. Therefore PNG has smaller interception time than PG, but this method may show unstable behavior for excessive values of the navigation constant [3]. We propose a new method "predictive pursuit guidance (PPG)" to ensure a stable guidance without excessive time delay. This algorithm is developed for an aerodynamic missile model which has realistic aerodynamic coefficient values and variations. Proposed guidance scheme is based on the estimation of target behavior using the target information measurable on the missile body. This scheme may have the characteristics of PG and PNG, depending on the relation between the prediction time and time-to-go. Homing missile guidance has some parametric uncertainties for the target maneuver and target behavior is observed through noisy measurements. In these cases, conventional control approaches may not be sufficient to obtain the tracking and interception. Fuzzy control has suitable properties to eliminate such difficulties. Fuzzy controller has been used in many fields where the controlled systems are uncertain or model-free. Recently, developed neuro-fuzzy techniques serve as possible approaches for the nonlinear flight control problems [4-6]. However, a limited number of papers have been adressed to the issue of fuzzy missile guidance design [7-9]. Proposed predictive pursuit guidance is designed considering the noise effect resulted from the thermal and radar detection sources at the system input. This noise affects the guidance system entirely. Fuzzy control is applied to the predictive pursuit guidance system to exploit the filtering property against to the noise effect. A tracking, control and interception performance obtained with this control scheme is compared with those of conventional PD control. This paper is organised as follows: First, the mathematical model of aerodynamic missile model is given. Second, the formulation and development of the predictive missile guidance are presented. After that, noise effect at the guidance system input and fuzzy controller for proposed method are briefly explained. Then, stability analysis is performed for proposed method using Lyapunov stability criteria. Finally, the results are evaluated comparing the performances of the proposed method to classical guidance methods such as PNG and PD pursuit guidance.

II. PREDICTIVE PURSUIT GUIDANCE

An aerodynamic missile-target model was derived and simulated in this study [10]. Some former researches [3] showed the existence of an inverse relation between the stability margin of PNG and navigation constant (n). This property causes the stability margin become smaller for large values of the navigation constant. The same work proved the tail pursuit guidance has the most stable behavior. On the other hand, the interception time is larger in PG because it guides the missile to the current position of the target without any prediction. The main purpose of this method is to realize as far as possible stable guidance with smaller interception time. The target behavior is estimated using variables measurable directly on the missile. These variables are LOS distance (R), closing velocity ($\dot{R}$), the angle between LOS and missile axis λ and its variation. A relation between prediction time (t_p) and time-to-go (ttg) may be formulated as:

$$ttg = \frac{R}{\dot{R}} \tag{1}$$

$$t_p = C_1 . ttg \tag{2}$$

where C_1 is a constant.

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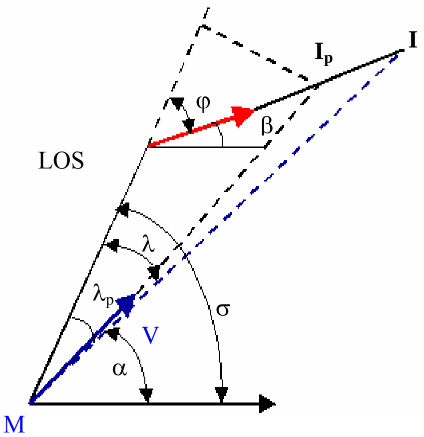


Fig. 1 Predictive Pursuit Guidance

As seen on Figure 1, if C_1=0 is chosen the pursuit guidance can be obtained due to the description in Section I, but if C1= 1 is taken, pursuit guidance turns into PNG. So, PNG can be used at launch phase to obtain fast, predictive guidance and it can be changed to the pursuit guidance at the interception phase to achieve the desired stability properties.

The variation of angle of attack $\dot{\alpha}$ can be measured using velocity gyroscope and the time derivation of $\dot{\alpha}$ leads to estimation of α. Then

$$\sigma = \alpha + \lambda \tag{3}$$

$$\dot{\sigma} = \dot{\alpha} + \dot{\lambda} \tag{4}$$

can be written. Figure 1 gives the equation of angle between LOS and V_T as

$$\varphi = a\tan\left(\frac{V_M \sin\lambda - R\dot{\sigma}}{V_M \cos\lambda + R}\right) \tag{5}$$

So, it can be written

$$\beta = \sigma - \varphi \tag{6}$$

using (3) and (5). Closing velocity of the missile and the variation of LOS angle σ are

$$\dot{R} = -V_M\left(\cos\lambda - \frac{V_T}{V_M}\cos\varphi\right) \tag{7}$$

$$\dot{\sigma} = \frac{V_M \sin\lambda - V_T \sin\varphi}{R} \tag{8}$$

(7) and (8) can be modified to an other form as written below

$$V_T \cos\varphi = \dot{R} + V_M \cos\lambda \tag{9}$$

$$V_T \sin\varphi = V_M \sin\lambda - R\dot{\sigma} \tag{10}$$

If (9) and (10) are arranged for V_T

$$V_T = \sqrt{(V_M \sin\lambda - R\dot{\sigma})^2 + (\dot{R} + V_M \cos\lambda)^2} \tag{11}$$

is obtained.

A. PD Control Design

Estimation of the target velocity V_T and target angle β allows obtaining the equations of the proposed guidance scheme. If $t_p < ttg$, an intermediate position of the target and the missile can be estimated. Then equations from Figure 1 are written as shown below:

$$\tan(\lambda_p) = \frac{V_T t_p \sin\varphi}{R + V_T t_p \cos\varphi} \tag{12}$$

$$\lambda_p = a\tan\left(\frac{V_T t_p \sin\varphi}{R + V_T t_p \cos\varphi}\right) \tag{13}$$

where λ_p is prediction angle. When (13) is arranged

$$V_T t_p \sin\varphi \cos\lambda_p = (R + V_T t_p \cos\varphi)\sin\lambda_p \tag{14}$$

can be found. If the expressions of V_T.cosφ and V_T.sinφ from (9) and (10) are replaced in (13)

$$\lambda p = a\tan\left(-\frac{R.t_p\dot{\sigma}}{R + \dot{R}.t_p}\right) \tag{15}$$

can be written. Time derivation of both sides of (14) with $\varphi = \sigma - \beta$ and β constant, will lead to

$$\dot{\lambda}_p = c\dot{\sigma} - d\dot{R} \tag{16}$$

where

$$\dot{\sigma} = \dot{\varphi} \tag{17}$$

$$c = \frac{1 + \tan\varphi \tan(\lambda_p)}{1 + \tan\varphi\tan(\lambda_p) + \dfrac{R}{V_T \cos\varphi . t_p}} \tag{18}$$

$$d = \frac{\dfrac{\tan(\lambda_p)}{V_T \cos\varphi t_p}}{1 + \tan\varphi\tan(\lambda_p) + \dfrac{R}{V_T \cos\varphi t_p}} \tag{19}$$

Then, control input *u(t)*, for PD control can be written as

$$u(t) = K_p.e + K_v.\dot{e} \tag{20}$$

where

$$e = (\lambda_p - \lambda) \quad (21)$$

$$\dot{e} = (\dot{\lambda}_p - \lambda) \quad (22)$$

and K_p and K_v are the control coefficients chosen for a required system dynamic behavior.

B. Fuzzy PD Design

Target position measurement is not precise and has a fuzzy distribution due to previously mentioned thermal and radar noises. This particularity allows the fuzzy controller is an alternative to the conventional deterministic PD control. The noise is modeled as a gaussian density function described as

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-(x-\mu)^2/(2\sigma^2)} \quad (23)$$

where μ is mean value, σ^2 is variance.

The input and output variables of the fuzzy controller are the linguistic variables because they take linguistic values. The input linguistic variables are error (e) and change of error ($\dot{e}$) and the linguistic output variable is the control signal u. The linguistic variables are expressed by linguistic sets. Each of these variables is assumed to take seven linguistic sets defined as negative big (NB), negative medium (NM), negative small (NS), zero (ZE), positive small (PS), positive medium (PM), positive big (PB). Triangular membership functions are preferred (Fig.2) to simplify the computation in real time operation. Boundary values of the universe of discourse are determined depending on the limit values of the gaussian density function to filter the noise effect.

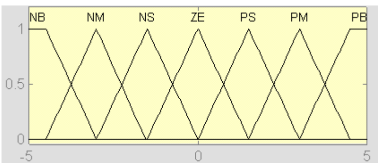


Fig. 2 Membership Function Type of the Variables

The rule base contains the collection of rules. A set of 49 rules in Table 1 has been used in this study to achieve our purpose. They have been constituted for fuzzy PD control scheme [11]. Minimum Mamdani type inference is used to obtain the best possible conclusions [9]. This type of inference allowed easy and effective computation and it is appropriate for real time control applications.

TABLE I
RULE BASE

u		$\dot{e}$						
		NB	NM	NS	ZE	PS	PM	PB
e	NB	NB	NS	PS	PB	PB	PB	PB
	NM	NB	NM	ZE	PM	PM	PB	PB
	NS	NB	NM	NS	PS	PM	PB	PB
	ZE	NB	NM	NS	ZE	PS	PM	PB
	PS	NB	NB	NM	NS	PS	PM	PB
	PM	NB	NB	NM	NM	ZE	PM	PB
	PB	NB	NB	NB	NB	NS	PS	PB

The outputs of the linguistic rules are fuzzy, but the guidance command must be crisp. Therefore, the outputs of the linguistic rules must be defuzzified before sending them to the actuators. The crisp control action is calculated here using the center of gravity (COG) defuzzification method. This criterion is computationally easier than the others and it supplies defuzzified output with better continuity.

III. CONTROL APPLICATIONS

Aerodynamic coefficients were evaluated by interpolating from tabulated values. Fuzzy control coefficients were scaled according to the system limitations, and then performance of the proposed control scheme was investigated by comparing with the other guidance methods. The criterions are the interception time and the noise rejection capability. The initial conditions for the missile are $\gamma(0) = 1.5$ rd., $\theta(0) = \gamma(0)$, $V_m(0) = 480$ m/s, $X_m(0) = 0$ m., $Y_m(0) = 3000$m., $q(0) = 0$ rd/s, $\delta_{zd}(0) = 0$ deg., $\delta_z(0) = 0$ deg. Target is maneuvered by changing β such as $\dot{\beta} = \frac{a_T}{V_T}$ where $a_T = 60$ m/s^2, $V_T = 240$ m/s. Firstly, a flexible fuzzy predictive pursuit guidance (FPPG) is applied to the system. During this application, PNG is used at launch phase to provide the fast heading, and then the intermediate t_p values are performed at the midcourse phase, finally the pursuit guidance is applied at the interception phase to obtain a stable behavior. Table 2 shows that how t_p is changed during simulation. Interception is obtained in 7.54 s in this application (Fig.3), this period is shorter than the interception time (7.68s) of the conventional pursuit (CP) as seen on Fig. 4. This value is very close to the PNG result given on Fig. 5. We would like to emphasize the shortest interception time is possible with PNG by choosing greater navigation constant, but in this case the stability problem may appear[3].

TABLE II
VARIATION OF THE PREDICTION TIME

Simulation Time (s)	**Prediction Time(s)**
0<=T<=2	t_p=ttg
2<T<=4	t_p=ttg/1.2
4<T<=6	t_p=ttg/2.4
6<T<=7	t_p=ttg/4.8
T>7	t_p=0

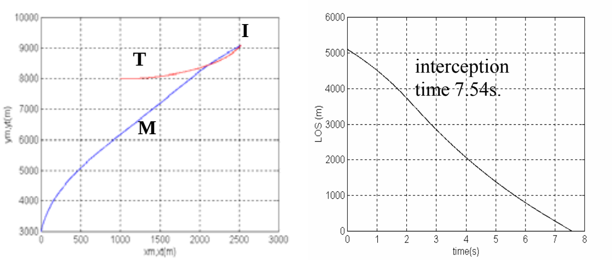


Fig. 3 Interception Trajectory and LOS Distance for FPPG

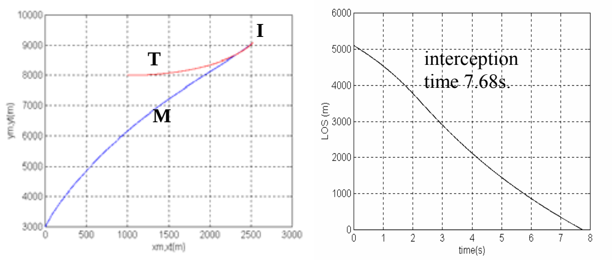


Fig.4 Interception Trajectory and LOS Distance for CP

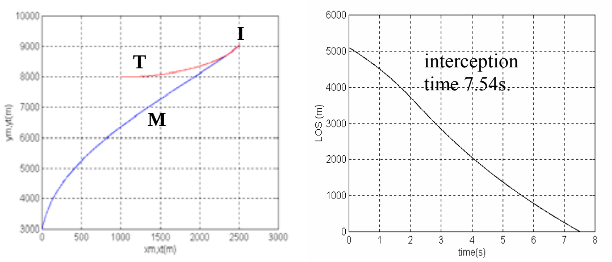
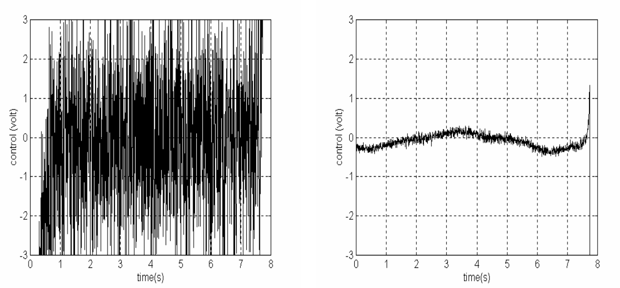


Fig. 5 Interception Trajectory and LOS Distance for PNG

Fig.6 shows the control performances of FPPG and CP. The noise rejection capability of the FPPG can be seen obviously on this figure.



CP FPPG

Fig. 6 Control Performance Comparison

IV. Stability Analysis

Lyapunov 2[th] method was used to analyze the stability of the guidance methods [3]. The stability concept will be mentioned here is not the missile stability, it is the stability concept of the interception problem. Lyapunov function includes the necessary criterion to track the target. The criteria are miss distance and the angle between LOS angle (σ) and flight path angle (γ). Then the state equations of the Lyapunov function are determined as [3]

$$x_1 = R.\dot{\sigma} \ , \ x_2 = \sigma - \gamma \tag{24}$$

The proposed Lyapunov function is:

$$V = k_1 \frac{x_1^2}{2} + k_2 \frac{x_2^2}{2} \qquad k_1 > 0, k_2 > 0 \tag{25}$$

The stability margin is defined for this Lyapunov function such as

$$k_1 x_1 + \frac{k_2 x_2}{V_m} > 0 \qquad s_m = a_m - a_s \tag{26}$$

$$k_1 x_1 + \frac{k_2 x_2}{V_m} < 0 \qquad s_m = -a_s - a_m \tag{27}$$

where s_m is the stability margin, a_m is the missile acceleration and a_s is the critical acceleration. a_s can be written as

$$a_s = \frac{k_1.x_1.a_t}{\left| k_1.x_1 + \dfrac{k_2.x_2}{V_m} \right|} + \frac{k_2.x_1.x_2 - k_1.\dot{R}.x_1^2}{R \left| k_1.x_1 + \dfrac{k_2.x_2}{V_m} \right|} \tag{28}$$

s_m >0 must be provided to obtain a stable guidance. Fig. 7 a shows that the (CP) satisfies the stability condition because s_m >0. Fig.7.b indicates the unstable PNG (navigation constant n=5) because s_m <0. If navigation constant is taken greater than this value, unstable margin for PNG will be greater [3]. FPPG with constant predictive time (t_p=ttg/2) satisfies the stability condition as shown in Fig.7.c. When this stability criterion is applied to the FPPG with flexible prediction time, the stability margin is obtained as shown in Fig.7.d. Since the PNG is applied at launch phase s_m can be smaller than zero. This case is possible because fast guidance is required and the interception stability is not important for this phase. When the missile closes to target, stability criterion must be satisfied and especially during interception phase. So, PNG is gradually changed into the pursuit guidance method at the interception phase in order to manage a stable guidance.

V. Conclusion

Fuzzy predictive pursuit guidance has been presented in this paper. A new method is proposed to realize the shortest interception time with a stable guidance law and is compared with the conventional guidance methods as the proportional navigation and the conventional tail pursuit. The simulation results showed that the proposed method managed a fast guidance. The stability analysis of this flexible application has shown that the stable guidance behavior is obtained at the interception phase. Because the stability is particularly significant at this phase the result is highly satisfying. The other results of the stability analysis showed that the predictive tail pursuit and the conventional tail pursuit have no unstability problem but the proportional navigation guidance behave out of the stability margin. The FPPG was compared with the CP. It is shown that the fuzzy controller has far better noise rejection performance than the classical version. From all results obtained, fuzzy predictive tail pursuit guidance law is suggested for the future studies in the homing missile area.

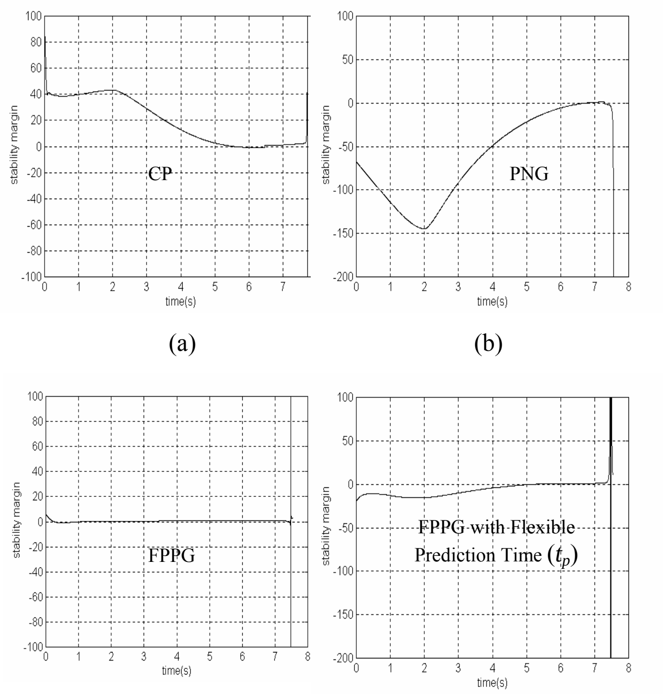


Fig.7 Stability Margins of the Guidance Methods

REFERENCES

[1] Mahaputra P.R., and Shukla U.S., "*Accurate Solution of Proportional Navigation for Maneuvering Targets*", IEEE Transactions on Aerospace and Electronic Systems, Vol. AE5-25, No.1, January 1989, pp. 81-86

[2] Mahaputra P.R., and Shukla U.S., "*The Proportional Navigation Dilemma- Pure or True?*", IEEE Transactions on Aerospace and Electronic Systems, Vol.26, No.2, March 1990, pp.382-392

[3] Acar Ş.U, and Özgören K., "*Trajectory Pursuit with the Target Tracker Guidance Methods*" (in Turkish), National Symposium of Automatic Control TOK 96 İstanbul, 28-29 March 1996, pp. 281-288B. Smith, "*An approach to graphs of linear forms (Unpublished work style)*," unpublished.

[4] Huang C., Tylock J., Engel S., and Whitson J., "*Comparison of Neural Network Based , Fuzzy Logic Based, and Numerical Nonlinear Inverse Flight Control*", Proceedings of the AIAA Guidance, Navigation and Control Conference, AIAA Washington DC, 1994, pp. 922-929.

[5] Geng Z.J., and McCullough C.L., "*Missile Control Using Fuzzy Cerebellar Model Arithmetic Computer Neural Networks*", Journal of Guidance, Control and Dynamics, Vol. 20, No.3, 1997, pp. 557-565.

[6] Lin C.L., and Chen Y.Y., "*Design of an Advanced Guidance Law Against High Speed Attacking Target*", Proceedings of the National Science Council, Part A, Vol.23, No.1, 1999, pp.60-74.

[7] Mishra K., Sarma I.G., and Swamy K.N., "*Performance Evaluation of the Fuzzy Logic Based Homing Guidance Schemes*", Journal of Guidance, Control and Dynamics, Vol.17, No.6, 1994, pp. 1389-1391.

[8] Gonsalves P.G., and Çağlayan A.K., "*Fuzzy Logic PID Controller for Missile Terminal Guidance*", Proceedings of 1995 IEEE International Symposium and Intelligent Control, IEEE Publications, Piscataway, NJ.1995, pp.377-382.

[9] Lin C.L., and Chen Y.Y., "*Design of Fuzzy Logic Guidance Law Against High Speed Target*", Journal of Guidance, Control and Dynamics, Vol.23, No.1, January-February 2000, pp. 17-25.

[10] M.R. Becan,"*Fuzzy Pursuit Guidance for Homing Missiles*" ICCI 2004, International Conference on Computational Intelligence, December 2004, İstanbul, pp.266-269

[11] Hoang L.H., and Maher H., "*Control of a Direct-Drive DC Motor by Fuzzy Logic*", IEEE Industry Applications Society, Vol. VI, 1993, pp. 732-738.