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RESEARCH OF NSV BASED ON OBSERVER

[1] HE NAI-BAO, [2]GAO QIAN

[1] Prof. School of Electrical Engineering, Huaihai Institute of Techology, China

[2] Assoc Prof. School of Electrical Engineering, Huaihai Institute of Techology, China

E-mail: [1] henaibao@126.com , [2]hhitzdh@126.com

ABSTRACT

An anti-disturbance method with fast adaptive disturbance observer was proposed for nearspace vehicle (NSV) with severely changed aero-dynamic parameters and external disturbances. First, a mathematical model was built for the NSV. Then, the anti-disturbance controller was designed with adaptive law based on adaptive parameters and compensation term for error. With the nonlinear exponential term in adaptive law, the approaching speed of disturbances observer was increased. And the proposed controller can make the system errors converge to zero in the finite time. The strict theoretical analysis was given for the closed-loop system. The simulation results showed the proposed control strategy for NSV with good performance in rapidity and convergence.

Keywords: *Nearspace Vehicle (NSV), Adaptive Observer (AO), Nonlinear System (NS)*

1. INTRODUCTION

NSV has many advantages such as good mobility, strong penetration ability, difficulty for the attack of conventional weapons and ability toachieve the long-range and high precision strike effect. Thus, some countries like Europe, America and Russia develop the techniques in this area, for example, X-43、X-51A[1]. Due to the special flight environment, lift-to-drag ratio varies are severely changed during its flight process. Then, NSV's flight motion is unstable and hard to be controlled. Meanwhile, the severely variation of the aerodynamic characteristics and the flying environment lead to the strong couple of multivariable time-vary and nonlinear uncertainty in kinematic model. The traditional control theory is difficult to control this dynamic model. Thus, the advanced control methods such as adaptive control[2], guaranteed cost control[3], robust control [4], neural network control [5] and fuzzy control [6] are widely used in the control system design of the NSV. The nonlinear and uncertainty of the system, aerodynamic characteristics perturbation, external interference are hard to be eliminated in the practical application. In order to eliminate the affect of the unknown interference, unmodeled dynamics and other uncertainty factors, the disturbance observer (DOB), which is used to approximate the compound disturbance of the system, has achieved perfect results in practical system. Sliding mode observer is used in [7] to achieve the fault diagnosis of the NSV. The application of the disturbance observer is studied in [8] for flight simulation system. Literature[9] uses nonlinear disturbance observer to improve the control performance of the guided missile. A high-gain observer is used to ensure excellent closed-loop performance and rapid stability of the system.

Based on the above analysis, this literature has presented a design method which uses fast adaptive disturbance observer to approximate compound interference of a vehicle control system. By means of design the parameter adaptive law and approximate error compensation term adaptive law, the corresponding controller of the flight control system is presented in this paper. And the approaching speed of interference observer is enhanced for composite interference. Hence, uniformly ultimate bound of disturbance observer system is guaranteed. Meanwhile, the rigorous theoretical analysis of the close loop system performance is shown in this paper.

The rest of this paper is organized as follows: In the next section, the form of dynamics model and analysis is presented. In section 3, the design of the NSV disturbance observers is proposed. Finally, conclusions are drawn in Section 4.

2. DYNAMICS MODEL AND ANALYSIS

According to the literature of the Langley research centre in America, a near space vehicle flight motion model with a variable wing structure

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is built in this paper. By ignoring the effects of gravity and the earth rotation, the kinematic model is described with the following 6 degrees of freedom and 12 state variables kinematic equations:

$$\dot{x} = V\cos\gamma\cos\chi. \quad (1)$$

$$\dot{y} = V\cos\gamma\sin\chi. \quad (2)$$

$$\dot{z} = -\dot{H} = -V\sin\gamma. \quad (3)$$

$$\dot{V} = \frac{1}{M}(Y\sin\beta - D - Mg\sin\gamma + T_x\cos\beta\cos\alpha + T_y\sin\beta + T_z\cos\beta\sin\alpha). \quad (4)$$

$$\dot{\chi} = \frac{1}{MV\cos\gamma}(L\sin\mu + Y\cos\mu\cos\beta + T_x\sin\mu\sin\alpha - T_x\cos\mu\sin\beta\cos\alpha + T_y\cos\mu\cos\beta - T_z\sin\mu\cos\alpha - T_z\cos\mu\sin\beta\sin\alpha). \quad (5)$$

$$\dot{\gamma} = \frac{1}{MV}\left[L\cos\mu - Y\sin\mu\cos\beta - Mg\cos\gamma + T_x(\sin\mu\sin\beta\cos\alpha + \cos\mu\sin\alpha) + T_z(\sin\mu\sin\beta\sin\alpha - \cos\mu\cos\alpha) - T_y\sin\mu\cos\beta\right]. \quad (6)$$

$$\dot{\alpha} = \frac{1}{MV\cos\beta} + \left[Mg\cos\gamma\cos\mu - L - T_x\sin\alpha + T_z\cos\alpha\right] + q - \tan\beta(p\cos\alpha + r\sin\alpha) \quad (7)$$

$$\dot{\beta} = \frac{1}{MV}\left[T_y\cos\beta - T_x\sin\beta\cos\alpha - T_z\sin\beta\sin\alpha + Y\cos\beta\right] + g\cos\gamma\sin\mu / V - r\cos\alpha + p\sin\alpha \quad (8)$$

$$\dot{\mu} = \sec\beta(p\cos\alpha + r\sin\alpha) + \frac{1}{MV}\left[L\tan\gamma\sin\mu + L\tan\beta + (Y + T_y)\tan\gamma\cos\mu\cos\beta - (T_x\cos\alpha + T_z\sin\alpha)\tan\gamma\cos\mu\sin\beta\right] + (T_x\sin\alpha - T_z\cos\alpha)(\tan\gamma\sin\mu + \tan\beta) - Mg\cos\gamma\cos\mu\tan\beta. \quad (9)$$

$$\dot{p} = I^p_{qr}qr + \dot{I}^p_p p + g^p_l(l_A + l_T). \quad (10)$$

$$\dot{q} = I^q_{pr}pr + \dot{I}^q_q q + g^q_m(m_A + m_T). \quad (11)$$

$$\dot{r} = I^r_{pq}pq + \dot{I}^r_r r + g^r_n(n_A + n_T). \quad (12)$$

In order to design a high-precision, high stability control system, six equations, which related with the attitude angle $\boldsymbol{\Omega} = [\alpha, \beta, \mu]$ and attitude angular velocity $\boldsymbol{\omega} = [p, q, r]$, is discussed in this paper. The states α, β, μ respectively present angle of attack, sideslip angle, roll angle, p 、 q 、 r respectively present rolling, pitching, yaw angle velocity, and $M_c(t)$ present control moment. According to singular perturbation theory, equation (7)-(12) can be transformed as fast gesture and slow loop equation:

$$\dot{\boldsymbol{\Omega}}(t) = \boldsymbol{f}_s(\boldsymbol{\Omega}(t)) + \boldsymbol{g}_s(\boldsymbol{\Omega}(t))\boldsymbol{\omega}(t). \quad (13)$$

$$\dot{\boldsymbol{\omega}}(t) = \boldsymbol{f}_f(\boldsymbol{\omega}(t)) + g_f(\boldsymbol{\omega}(t))\boldsymbol{M}_C(t) \quad (14)$$

3. DESIGN OF THE NSV SELF-ADOPTION DISTURBANCE OBSERVER

Taking a kind of higher order nonlinear uncertain systems into consideration:

$$\begin{aligned} \dot{x}_1 &= x_2 \\ &\vdots \\ \dot{x}_{n-1} &= x_n \\ \dot{x}_n &= \alpha(\boldsymbol{x}) + \Delta\alpha(\boldsymbol{x}) + [\beta(\boldsymbol{x}) + \Delta\beta(\boldsymbol{x})]u + d(t) \end{aligned} \quad (15)$$

where $\Delta\alpha(\boldsymbol{x})$ 、 $\Delta\beta(\boldsymbol{x})$ are the uncertainty term, $d(t)$ is external disturbance, u is the control input. On the basis of the approximation capability of the fuzzy control, compound interference is supposed to be $\Omega_x(\boldsymbol{x}, u) = \Delta\alpha(\boldsymbol{x}) + \Delta\beta(\boldsymbol{x}) + d(t)$. Fuzzy logic system is severed as a kind of disturbance observer to approximate the compound interference on-line. Therefore, define a dynamic observation system as follows:

$$\dot{\mu} = -\sigma\mu + p(\boldsymbol{x}, u, \hat{\boldsymbol{\theta}}) \quad (16)$$

where $p(\boldsymbol{x}, u, \hat{\boldsymbol{\theta}}) = \sigma x_n + \alpha(\boldsymbol{x}) + \beta(\boldsymbol{x})u + \hat{\Omega}_x(\boldsymbol{x}, u|\hat{\boldsymbol{\theta}})$

.

When the control law $u = \frac{\upsilon - \alpha(\boldsymbol{x}) - \hat{\Omega}_x(\boldsymbol{x}, u|\hat{\boldsymbol{\theta}})}{\beta(\boldsymbol{x})}$, the entire loop-system is uniformly ultimately bounded. Inspired from, taking various uncertainty and external interference during the NSV's flight into consideration, Terminal sliding mode control law is acted as the main control law. At the same time, self-adaptive disturbance observer as compensation control term is designed. And it has an effect on the slow and fast control loop of the automatic flight control system. The structure chart of the control system is shown as follows:

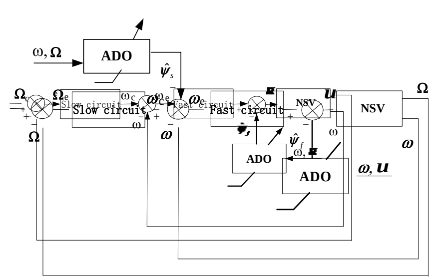

Fig.1 Scheme of ADO closed-loop control system

3.1The design of adaptive interference observer for the uncertain NSV slow loop

Considering the uncertainty influences on NSV, the slow loop motion equation of slow loop is given as follows:

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$$\dot{\boldsymbol{\Omega}}(t) = \boldsymbol{f}_s(\boldsymbol{\Omega}(t)) + \Delta \boldsymbol{f}_s(\boldsymbol{\Omega}(t)) + \boldsymbol{g}_s(\boldsymbol{\Omega}(t))\boldsymbol{\omega}(t) \qquad (17)$$

In this equation, $\Delta \boldsymbol{f}_s(\boldsymbol{\Omega}(t))$ represents uncertain part to $\boldsymbol{f}_s(\boldsymbol{\Omega}(t))$, $\boldsymbol{\omega}(t)$ is the attitude angular velocity. In general, there is an assumption before designing the adaptive disturbance observer.

Hypothesis 1[10]: there exists $\boldsymbol{\Omega}$ in a compact set. The equation

$$\boldsymbol{\theta}^* = \arg \min_{\hat{\theta} \in \Theta_\theta} \left[\sup_{\boldsymbol{\Omega} \in \Theta_\Omega} \left| \boldsymbol{\psi}(\boldsymbol{\Omega},\boldsymbol{\omega}) - \hat{\boldsymbol{\psi}}(\boldsymbol{\Omega}|\hat{\boldsymbol{\theta}}) \right| \right] \qquad (18)$$

is tenable, and it meets the optimal parameter vector in a convex set

$$\boldsymbol{\Theta}_\theta = \{ \boldsymbol{\theta} | \ \|\boldsymbol{\theta}\| \le b_\theta \} \qquad (19)$$

where b_θ is designing parameter, $\boldsymbol{\psi}(\boldsymbol{\Omega},\boldsymbol{\omega})$ is disturbance.

Lemma 1 : Suppose that the continuous function satisfies the following differential inequality

$$\dot{\hbar}(t) \le -\alpha \hbar(t) - \beta \hbar^{q/p}(t), \qquad \forall t \ge t_0 \qquad (20)$$

And the $\alpha, \beta > 0$, $p > q$, p,q are positive odd. Then $\hbar(t)$ would converge to zero in the limited time,

$$t_r = t_0 + \frac{p}{\alpha(p-q)} \ln \frac{\alpha \hbar(t_0)^{(p-q)/p} + \beta}{\beta} \qquad (21)$$

Fuzzy logic system is chose to approach the uncertainty disturbances. Its expression is given as follows:

$$y(\boldsymbol{\Omega}) = \frac{\sum_{i=1}^{r} y^i (\sum_{j=1}^{n} \mu_{A_j^i}(\boldsymbol{\Omega}_j))}{\sum_{j=1}^{n} \mu_{A_j^i}(\boldsymbol{\Omega}_j)} = \hat{\boldsymbol{\theta}}^T \xi(\boldsymbol{\Omega}) \qquad (22)$$

where $\mu_{A_j^i}(\boldsymbol{\Omega}_j)$, $\xi(\boldsymbol{\Omega})$, $\hat{\boldsymbol{\theta}}^T$ represent membership function, basis function, adjustable parameter vector. Respectively, $y(\boldsymbol{\Omega})$ is output of fuzzy system. For the system(17), the dynamic observation system is designed as:

$$\dot{\boldsymbol{\mu}}_s = \sigma(\boldsymbol{\Omega} - \boldsymbol{\mu}_s) + \boldsymbol{f}_s(\boldsymbol{\Omega}(t)) + \boldsymbol{g}_s(\boldsymbol{\Omega}(t))\boldsymbol{\omega}(t)$$
$$+\boldsymbol{\theta}_0{}^T \xi(\boldsymbol{\Omega},\boldsymbol{\omega}) + \boldsymbol{\chi}_\theta + \boldsymbol{\chi}_\varepsilon \qquad (23)$$

where $\sigma > 0$ is design parameters, $\boldsymbol{\theta}_0$ is estimated value of $\boldsymbol{\theta}^*$, $\boldsymbol{\chi}_\theta$, $\boldsymbol{\chi}_\varepsilon$ are the adaptive control input, and

$$\chi_\varepsilon = \hat{\pi}^2(\boldsymbol{\varpi}_s)/[\hat{\pi}(\|\boldsymbol{\varpi}_s\|) + a_1] \qquad (24)$$

$$\chi_\theta = \hat{\upsilon}^2(\boldsymbol{\varpi}_s)\xi^T(\boldsymbol{\Omega},\boldsymbol{\omega})/[\hat{\upsilon}(\|\boldsymbol{\varpi}_s\|)\|\xi(\boldsymbol{\Omega},\boldsymbol{\omega})\| + a_2] \cdot \xi(\boldsymbol{\Omega},\boldsymbol{\omega}) \qquad (25)$$

$\boldsymbol{\varpi}_s$ is slow loop interference observation error, $a_1, a_2 > 0$ are design parameters, $\hat{\upsilon}$ and $\hat{\pi}$ are the estimate of υ, π which satisfy the equation

$$\|\varepsilon(\boldsymbol{\Omega},\boldsymbol{\omega})\| \le \pi, \quad \|\tilde{\boldsymbol{\theta}}\| = \|\boldsymbol{\theta}^* - \boldsymbol{\theta}_0\| \le \upsilon \qquad (26)$$

Slow loop interference observation error is expressed as:

$$\dot{\boldsymbol{\varpi}}_s = -\sigma \boldsymbol{\varpi}_s + \tilde{\boldsymbol{\theta}}^T \xi(\boldsymbol{\Omega},\boldsymbol{\omega}) + \varepsilon(\boldsymbol{\Omega},\boldsymbol{\omega}) - \boldsymbol{\chi}_\theta - \boldsymbol{\chi}_\varepsilon \qquad (27)$$

In order to rapidly tracl the the guidance signal, sliding mode control surfaces are defined as follows:

$$\boldsymbol{\varPi} = \boldsymbol{\Omega}_e + \int_0^t (c_1 \boldsymbol{\Omega}_e + c_2 \boldsymbol{\Omega}_e^{q_1/p_1}) d\tau = 0 \qquad (28)$$

where $\boldsymbol{\Omega}_e$ is tracking error,

$c_1, c_2 > 0$, $p_1 > q_1 > 0$

and p_1, q_1 are positive odd.

Then slow loop nominal Terminal sliding mode control law and adaptive disturbance observer design are given in theorem 1.

Theorem 1: considering Near space vehicles slow loop system (17), for interference observation error dynamic system(27), the interference observation error is consistent ultimately bounded, under the action of the control law(29), parameter adaptive control law(30) and (31).

$$\boldsymbol{\omega}(t) = \boldsymbol{g}_s^{-1}(-\boldsymbol{f}_s(\boldsymbol{\Omega}(t)) - \boldsymbol{\theta}_0^T \xi(\boldsymbol{\Omega},\boldsymbol{\omega}) - c_1 \boldsymbol{\Omega}_e - c_2 |\boldsymbol{\Omega}_e|^{q_1/p_1} sign(\boldsymbol{\Omega}_e)$$
$$+ \dot{\boldsymbol{\Omega}}_c - \chi_\theta - \chi_\varepsilon - \zeta_1 \boldsymbol{\varPi} - \zeta_2 |\boldsymbol{\varPi}|^{r_1/\delta_1} sign(\boldsymbol{\varPi})) \qquad (29)$$

$$\dot{\hat{\pi}} = \gamma_1 [\|\boldsymbol{\varpi}_s\| - h_1(\hat{\pi} - \pi_0)] \qquad (30)$$

$$\dot{\hat{\upsilon}} = \gamma_2 [(\|\boldsymbol{\varpi}_s\|)\|\xi(\boldsymbol{\Omega},\boldsymbol{\omega})\| - h_2(\hat{\upsilon} - \upsilon_0)] \qquad (31)$$

where π_0, υ_0 are the initial value of π, υ , $h_1, h_2, \zeta_1, \zeta_2$ are design parameter and bigger than zero, $\gamma_1, \gamma_2 > 0$ are learning rate, $p_1 > q_1 > 0$ are positive odd.

Proof: For the system (17), Lyapunov function is defined as

$$V = \frac{1}{2} \boldsymbol{\varpi}_s{}^T \boldsymbol{\varpi}_s + \frac{1}{2\gamma_1} \tilde{\pi}^2 + \frac{1}{2\gamma_2} \tilde{\upsilon}^2$$

(32)

Its derivation is

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$$\dot{V} \le -\sigma \boldsymbol{\varpi}_s^T \boldsymbol{\varpi}_s + a_1 + a_2 + \tilde{\pi} h_1(\hat{\pi} - \pi_0) + \tilde{\upsilon} h_2(\hat{\upsilon} - \upsilon_0) \tag{33}$$

$$\dot{V} \le -\sigma \boldsymbol{\varpi}_s^T \boldsymbol{\varpi}_s + a_1 + a_2 - \frac{h_1 \tilde{\pi}^2}{2} + \frac{h_1(\pi - \pi_0)^2}{2} - \frac{h_2 \tilde{\upsilon}^2}{2} + \frac{h_2(\upsilon - \upsilon_0)^2}{2} \tag{34}$$

When $\|\boldsymbol{\varpi}_s\| > \sqrt{\frac{2a_1 + 2a_2 + h_1(\pi - \pi_0)^2 + h_2(\upsilon - \upsilon_0)^2}{2\sigma}}$, $\dot{V} < 0$ is obtained, the interference observation error is uniformly bounded. The closed loop system tracking error convergence condition is given by the theorem 2.

Theorem 2: Taking Near space vehicles slow loop system(17) into account, for interference observation error dynamic system(27), the closed loop system tracking error converges to a bounded area, under the action of the control law(35), parameter adaptive control law(30) and (31) .

$$\boldsymbol{\omega}(t) = \boldsymbol{g}_s^{-1}(-\boldsymbol{f}_s(\boldsymbol{\Omega}(t)) - \boldsymbol{\theta}_0^T \xi(\boldsymbol{\Omega}, \boldsymbol{\omega}) - c_1 \boldsymbol{\Omega}_e - c_2 |\boldsymbol{\Omega}_e|^{q_1/p_1} sign(\boldsymbol{\Omega}_e)$$
$$+ \dot{\boldsymbol{\Omega}}_c - \boldsymbol{\chi}_\theta - \boldsymbol{\chi}_\varepsilon - \zeta_1 \boldsymbol{\varPi} - \zeta_2 |\boldsymbol{\varPi}|^{\tau_1/\delta_1} sign(\boldsymbol{\varPi})) \tag{35}$$

where $\delta_1 > \tau_1 > 0$ are odd, ζ_1 and ζ_2 are design constant greater than zero, $\boldsymbol{\Omega}_e = \boldsymbol{\Omega} - \boldsymbol{\Omega}_c$, $\boldsymbol{\Omega}_c$ is given tracking signal.

Proof: Lyapunov function is defined as:

$$V = \frac{1}{2} \boldsymbol{\varPi}^T \boldsymbol{\varPi} \tag{36}$$

$$\dot{V} \le -\zeta_1 \|\boldsymbol{\varPi}\|^2 - (\zeta_2 \|\boldsymbol{\varPi}^{\tau_1/\delta_1}\| - \bar{\varepsilon}) \|\boldsymbol{\varPi}\|$$

Choosing $\zeta_2 \|\boldsymbol{\varPi}^{\tau_1/\delta_1}\| - \bar{\varepsilon} \ge p > 0$, where $\bar{\varepsilon} \ge \|\Delta \boldsymbol{f}_s(\boldsymbol{\Omega}(t)) - \boldsymbol{\theta}_0^T \xi(\boldsymbol{\Omega}, \boldsymbol{\omega}) - \boldsymbol{\chi}_\theta - \boldsymbol{\chi}_\varepsilon\|$, we have

$$\dot{V} \le -2\zeta_1 V - \sqrt{2} p V^{1/2} \tag{37}$$

According to the lemma 1, $\boldsymbol{\varPi}$ in the limited time will converge to a small area Δ_1, and

$$\Delta_1 = \left\{ \boldsymbol{\varPi} \,|\, \|\boldsymbol{\varPi}^{\tau_1/\delta_1}\| \le \frac{\bar{\varepsilon} + p}{\zeta_2} \right\}$$

$$t_1 = \frac{1}{\zeta_1} \ln \frac{2\zeta_1 V(t_0)^{1/2} + \sqrt{2} p}{\sqrt{2} p}$$

3.2The design of the fast adaptive disturbance observer for NSV

Taking disturbed NSV fast loop system into account, it not only concerns the stability and anti-interference, but also concerns the real-time and fast for a high-speed flight NSV control system. Because of the harsh environment during the NSV flying, it is important to eliminate the effect of the compound interference quickly. And the accuracy is also necessary.

First, with fuzzy system $\psi(\boldsymbol{\omega}, \boldsymbol{u}) = \boldsymbol{\theta}^{*T} \xi(\boldsymbol{\omega}, \boldsymbol{u}) + \boldsymbol{\varepsilon}(\boldsymbol{\omega}, \boldsymbol{u})$ approximation, fast loop dynamic interference observing system is designed to observe the fast loop compound interference.

$$\dot{\boldsymbol{\mu}}_f = \boldsymbol{f}_f(\boldsymbol{\omega}, t) + \boldsymbol{g}_f(\boldsymbol{\omega}, t) \boldsymbol{u}(t) + \alpha(\boldsymbol{\omega} - \boldsymbol{\mu}_f)$$
$$+ \beta(\boldsymbol{\omega} - \boldsymbol{\mu}_f)^{\tau/\delta} + \boldsymbol{\vartheta}_\theta + \boldsymbol{\vartheta}_\varepsilon + \boldsymbol{\theta}^T \xi(\boldsymbol{\omega}, \boldsymbol{u}) . \tag{38}$$

where $\boldsymbol{\varpi} = \boldsymbol{\omega} - \boldsymbol{\mu}_f$ is observe error, $\boldsymbol{\theta}$ represents the estimate to the $\boldsymbol{\theta}^*$, $\boldsymbol{\vartheta}_\theta, \boldsymbol{\vartheta}_\varepsilon$ is the self-adopt control law designed which satisfies equation (42),(43), $\alpha, \beta > 0$ is design parameter, $\delta > \tau > 0$ is positive odd.

According to the definition of the observer error:

$$\dot{\boldsymbol{\varpi}} = -\alpha \boldsymbol{\varpi} - \beta \boldsymbol{\varpi}^{\tau/\delta} + \tilde{\boldsymbol{\theta}}^T \xi(\boldsymbol{\omega}, \boldsymbol{u}) + \varepsilon(\boldsymbol{\omega}, \boldsymbol{u}) - \boldsymbol{\vartheta}_\theta - \boldsymbol{\vartheta}_\varepsilon . \tag{39}$$

where $\|\boldsymbol{\varepsilon}(\boldsymbol{\omega}, \boldsymbol{u})\| \le \lambda$, $\|\tilde{\boldsymbol{\theta}}\| = \|\boldsymbol{\theta}^* - \boldsymbol{\theta}\| \le \rho$, suppose $\hat{\lambda}, \hat{\rho}$ represent the estimate of the λ, ρ , so $\tilde{\lambda} = \lambda - \hat{\lambda}$, $\tilde{\rho} = \rho - \hat{\rho}$。

Theorem 3: Taking the NSV fast loop interference system into account, the observation error $\boldsymbol{\varpi}$ of the interference observation error dynamic system(39) is uniformly bounded under the affect of the parameter self-adaptive control law(40)、(41)、(42)and(43).

$$\dot{\hat{\lambda}} = w_1[\|\boldsymbol{\varpi}\| + \|\boldsymbol{\varpi}^{\tau/\delta}\| - k_1(\hat{\lambda} - \lambda_0)] \tag{40}$$

$$\dot{\hat{\rho}} = w_2[(\|\boldsymbol{\varpi}\| + \|\boldsymbol{\varpi}^{\tau/\delta}\|)\|\xi(\boldsymbol{\omega}, \boldsymbol{u})\| - k_2(\hat{\rho} - \rho_0)] . \tag{41}$$

$$\boldsymbol{\vartheta}_\varepsilon = \hat{\lambda}^2 (\boldsymbol{\varpi} + \boldsymbol{\varpi}^{\tau/\delta}) / [\hat{\lambda}(\|\boldsymbol{\varpi}\| + \|\boldsymbol{\varpi}^{\tau/\delta}\|) + r_1] . \tag{42}$$

$$\boldsymbol{\vartheta}_\theta = \hat{\rho}^2 (\boldsymbol{\varpi} + \boldsymbol{\varpi}^{\tau/\delta}) \xi^T(\boldsymbol{\omega}, \boldsymbol{u}) / [\hat{\rho}(\|\boldsymbol{\varpi}\| + \|\boldsymbol{\varpi}^{\tau/\delta}\|)$$
$$\|\xi(\boldsymbol{\omega}, \boldsymbol{u})\| + r_2] \cdot \xi(\boldsymbol{\omega}, \boldsymbol{u}) \tag{43}$$

where λ_0, ρ_0 represent the initial value of λ, ρ , $r_1, r_2 > 0$, $k_1, k_2 > 0$ are the designed parameters , $w_1, w_2 > 0$ is learn rate.

Proof: Lyapunov function is defined as:

$$V = \frac{1}{2} \boldsymbol{\varpi}^T \boldsymbol{\varpi} + \frac{\delta}{\tau + \delta} (\boldsymbol{\varpi}^{(\tau+\delta)/(2\delta)})^T \boldsymbol{\varpi}^{(\tau+\delta)/(2\delta)} + \frac{1}{2w_1} \tilde{\lambda}^2 + \frac{1}{2w_2} \tilde{\rho}^2 . \tag{44}$$

The derivation is:

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$$\dot{V} = (\boldsymbol{\varpi} + \boldsymbol{\varpi}^{\tau/\delta})^T \dot{\boldsymbol{\varpi}} + \frac{1}{w_1}\tilde{\lambda}\dot{\tilde{\lambda}} + \frac{1}{w_2}\tilde{\rho}\dot{\tilde{\rho}}$$
$$\leq -\alpha\|\boldsymbol{\varpi}\|^2 + r_1 + r_2 - \frac{k_1\tilde{\lambda}^2}{2} + \frac{k_1(\lambda-\lambda_0)^2}{2} - \frac{k_2\tilde{\rho}^2}{2} + \frac{k_2(\rho-\rho_0)^2}{2}.$$

When

$$\|\varpi\| > \sqrt{\frac{2r_1 + 2r_2 + k_1(\lambda-\lambda_0)^2 + k_2(\rho-\rho_0)^2}{2\alpha}},$$

$\dot{V} < 0$, the interference observation error is uniformly bounded.

Theorem 4: Taking the NSV fast loop interference system into account, the closed-loop system tracking error of the interference observation error dynamic system (39), which is under the affect of the parameter self-adaptive control law (42), (43) and control law (45), converges to a bounded region.

$$\boldsymbol{u} = \boldsymbol{g}^{-1}(\omega(t))[-\boldsymbol{f}(\omega(t)) - \theta^T\xi(\omega,u) - \vartheta_\theta - \vartheta_\varepsilon + \dot{\omega}_d - b_1\omega_e] \quad (45)$$

where $\delta > \tau > 0$, $\delta_1 > \tau_1 > 0$ and it is positive odd, $\boldsymbol{\omega}_e = \boldsymbol{\omega} - \boldsymbol{\omega}_d$, $\boldsymbol{\omega}_d$ represent the given trace command, $b_1, b_2, j_1, j_2 > 0$ are the designed const. The proving process is similar to Theorem 2.

4. CONCLUSION

The convergence velocity of the traditional observation is low. In order to attain the quick and steady control when NSV is under the condition of indeterminacy and disturbance, the adaptive learning rate is modified, the approximation speed of the interference observing system to the compound interference is enhanced and the system performance is rigorously analyzed. By means of changing the adaptive learning rate, the interference observing system for the compound interference and the convergence precision of the error system are ameliorated. The simulation well testified the effectiveness of this method.

REFRENCES:

[1] CAITLIN H, " USAF successfully tests X-51A WaveRider", *Jane's defence weekly*, Vol. 47, No.22, January 2010, pp. 54-59.

[2] LISA F, ANDREA S, "Adaptive restricted trajectory tracking for a non-minimum phase hypersonic vehicle model", *Automatica*, Vol. 48, No.7, 2012, pp. 1248–1261.

[3] HU X, WU L, HU C. "Fuzzy guaranteed cost tracking control for a flexible air-breathing hypersonic vehicle", *IET Control Theory Appl*, Vol.6, No.9, 2012, pp. 1238–1249.

[4] LISA F, ANDREA S ,MICHAEL A. "Nonlinear robust adaptive control of flexible Air-breathing hypersonic vehicles", *Journal of Guidance, Control and Dynamics*, Vol. 32, No.2, 2009, pp. 402-417

[5] CHEN, M, JIANG C S,WU Q X, "Disturbance-observer-based robust flight control for hypersonic vehicles using Neural Networks", *Advanced Science Letters*, Vol. 4, No.5, 2011, pp. 1771-1775.

[6] GAO D X, SUN Z Q , "Fuzzy tracking control design for hypersonic vehicles via T-S model", *SCIENCE CHINA Information Sciences*, Vol. 54, No.3, 2011, pp. 521-528.

[7] SHEN Q, JIANG B , COCQUEMPOT V, "Fault diagnosis and estimation for near-space hypersonic vehicle with sensor faults", *Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering*, Vol. 1, No.1, 2012, pp. 1-12.

[8] WU Y J, LIU X D, TIAN D P. " Research of compound controller for flight simulator with disturbance observer ", *Chinese Journal of Aeronautics*, Vol. 24, No.5, 2011, pp. 613-621.

[9] CHEN W H. "nonlinear disturbance observer enhanced dynamic inversion control of missiles[", *J Guid Contr Dynam*, ,No.26, 2003, pp. 161-166.

[10] B.N. Singh, Bhim Singh, Ambrish Chandra, and Kamal Al-Haddad, "Digital Implementation of an Advanced Static VAR Compensator for Voltage Profile Improvement, Power Factor Correction and Balancing of Unbalanced Reactive Loads", *Electric Power Energy Research*, Vol. 54, No. 2, 2000, pp. 101-111.