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Smart tracking design for aerial system via fuzzy nonlinear criterion

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Abstract. A new intelligent adaptive control scheme was proposed that combines the control based on interference observer and fuzzy adaptive s-curve for flight path tracking control of unmanned aerial vehicle (UAV). The most important contribution is that the control configurations don't need to know the uncertainty limit of the vehicle and the influence of interference is removed. The proposed control law is an integration of fuzzy control estimator and adaptive proportional integral (PI) compensator with input. The rated feedback drive specifies the desired dynamic properties of the closed control loop based on the known properties of the preferred acceleration vector. At the same time, the adaptive PI control compensate for the unknown of perturbation. Additional terms such as s-surface control can ensure rapid convergence due to the non-linear representation on the surface and also improve the stability. In addition, the observer improves the robustness of the adaptive fuzzy system. It has been proven that the stability of the regulatory system can be ensured according to linear matrix equality based Lyapunov's theory. In summary, the numerical simulation results show the efficiency and the feasibility by the use of the robust control methodology.

Keywords: adaptive fuzzy system; disturbance-observer-based control; Lyapunov energy function; unmanned aerial vehicle

1. Introduction

In space research, navigation, guidance and control of UAVs have received much attention. To solve this problem, scientists have now made every effort to develop advanced control technologies with intelligence, adaptability, rapid convergence and robustness. In recent decades, however, various control technologies that are very well suited to space technology have been used for motion control. These include PD/PID control (Jalving 1994), self-optimizing control (Goheen and Jefferys 1990), linear quadratic Gaussian control (LQG) (Silvestre *et al*. 2002); planning control (Silvestre *et al*. 2002, Kumar *et al*. 2007), retrospective method (Li and Lee 2005), μ-synthesis (Campa *et al*. 1998), H^{∞} control (Feng and Allen 2004), convex linear matrix inequality (LMI) (Kim 2015), suboptimal control (Geranmehr and Nekoo 2015) and control based on the Riccati forms (Naik and Singh 2007).

In the last few decades, intelligent control methods such as fuzzy logic control (FLC) and neural network (NN) control have been used successfully in various applications. Many control systems that implement standard algorithms PID, fuzzy, genetic, neural network, etc. have been developed to achieve the tracking design for aerial systems. Many researchers have developed manual, differential, single pulse, electronic, automatic tracking, left and right, cone and step tracking methods to track the signal source. The performance of standard algorithms and tracking methods used to track signal sources are discussed. The rapid development of digital computer control systems requires the calculation of control signals. In this respect, the developed method of intelligent control has received a great deal of attention. Many excellent design methods have been proposed for the FLC system and a number of efficient methods are recommended to address durability, stability and time delay. Intelligent control technology, such as the adaptive method and the adaptive dynamic programming method, is believed to be an optimal tool in analyzing the nonlinear systems. Intelligent control technology can be very useful in solving control problems in motion control of drones. Examining the existing literature, the researchers found that intelligent control is particularly attractive to a class of highly coupled non-linear insecure systems because of their attractive special properties, such as those not suitable for systems that work well. In a mathematical form based on the experience of human experts, this heuristic method is simple and easy to implement. Intelligent control methods usually include neural network fuzzy logic (FL) (Kim 2015), genetic algorithm (GA) (Geranmehr and Nekoo 2015) and adaptive repetitive neuro-fuzzy control technology (Feng and Allen 2004). It has stronger resistance to uncertainty about fluid dynamics and excellent anti-interference ability. The known shortcomings of intelligent control are listed below: Conventional obscure control requires specialized knowledge or huge computing time

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only for the required performance. In neural network (NN) control, the approximation of time lag makes the theory not applicable. Although BA-based controls are commonly used in most studies as a secondary balance tuner, the stability of BA-based control systems cannot be guaranteed. From a control perspective, a sophisticated model-based controller may not be able to handle parameter uncertainties and disturbances right away and may result in poor tracking performance.

In this paper, a novel control program is utilized for the trajectory of UAVs in 3D space, which can be regarded as the extension of the proposed control system (Mohammadi *et al*. 2013). The proposed composite control technology is the integration, namely nominal control such as the concept disturbance estimator and robust fuzzy PI compensator. By integrating the non-linear perturbation observer into the S-plane control method, the known required acceleration vector and the estimated perturbed expression can be used at the infinite convergence time to ensure the required path tracking response to compensate for the unknown impacts. Unlike the existing adaptive fuzzy control program, this scheme indirectly extracts interference information from the tracking error and can overcome the influence of model parameter size and external changes.

2. System description and preliminary problem

Usually based on the Newton-Euler formula to describe the six-freedom (6-DoF) UAV motion non-linear equation, which is described in a compact standard form as follows

$$M(\nu)\dot{\nu} + C(\nu)\nu + D(\nu)\nu + g(\eta) = \tau \tag{1}$$

where $\eta = [x, y, z, \varphi, \theta, \psi]T \in < R^6$ represents the position and direction vector given by the Euler angle relative to the inertial system, $\nu = [u, v, w, p, q, r]T \in < R^6$ is linear and angular velocities; $M(\nu) \in < R^{6\times6}$ is the inert matrix, $g(\eta) \in < R^6$ is the combination of gravity and buoyancy, and $\tau \in < R^6$ is the control input vector in the system that describes force and torque stress. The mapping between the two coordinate systems is derived from the transformation of Euler angles because

$$\dot{\eta} = J(\eta)\nu \tag{2}$$

Where $J(\eta) \in < R^{6\times6}$ spatial transformation matrix in a non-singular form is

$$J(\eta) = \begin{bmatrix} J_1(\eta_2) & 0 \\ 0 & J_2(\eta_2) \end{bmatrix} \tag{3}$$

$$J_1(\eta_2) = \begin{bmatrix} \cos\psi\cos\theta & -\sin\psi\cos\phi + \cos\psi\sin\theta\sin\phi & -\sin\psi\sin\phi + \cos\psi\sin\theta\cos\phi \\ \sin\psi\cos\theta & -\cos\psi\cos\phi + \sin\psi\sin\theta\sin\phi & -\cos\psi\sin\phi + \sin\psi\cos\phi \\ -\sin\theta & -\cos\theta\sin\phi & \cos\theta\cos\phi \end{bmatrix} \tag{4}$$

$$J_2(\eta_2) = \begin{bmatrix} 1 & \sin\phi\tan\theta & \cos\phi\tan\theta \\ 0 & \cos\phi & -\sin\phi \\ 0 & \sin\phi/\cos\theta & \cos\phi/\cos\theta \end{bmatrix} \tag{5}$$

Among them, $J_1(\eta_2) \in < R^{3\times3}$ represents the linear velocity transformation matrix, and $J_2(\eta_2) \in < R^{3\times3}$ represents the rotation of the angular velocity. The representation of UAV dynamics in a fixed earth frame is determined by the following transformation.

$$\dot{\eta} = J(\eta)\nu \quad \Leftrightarrow \quad \nu = J(\eta) - 1\dot{\eta} \tag{6}$$

Taking the derivative of the generalized coordinates representing the position and orientation

$$\ddot{\eta} = J(\eta)\dot{\nu} + \dot{J}(\eta)\nu \tag{7}$$

$$\begin{aligned} &MJ(\eta)^1\ddot{\eta} + \left(C(\nu) - MJ(\eta)^{-1}\dot{J}(\eta)\right)J(\eta)^{-1}\dot{\eta} \\ &+D(\nu)J(\eta)^1\dot{\eta} + g(\eta) = \tau \end{aligned} \tag{8}$$

Then

$$M_\eta(\eta)\ddot{\eta} + C_\eta(\nu,\eta)\dot{\eta} + D_\eta(\nu,\eta)\dot{\eta} + G_\eta(\eta) = \tau_\eta \tag{9}$$

$$M_\eta(\eta) = J(\eta)^1 MJ(\eta)^{-1} - C_\eta(\nu,\eta) \tag{10}$$

$$= J(\eta)^{1h}C(\nu) - MJ(\eta)^{-1}\dot{J}(\eta)^i J(\eta)^{-1} - D_\eta(\nu,\eta) \tag{11}$$

The dynamic properties of UAVs are consistent with the following structural characteristics of the grounding vector form:

Property 1: The inertia matrix M_η is symmetric and positive definite, i.e.

$$M_\eta(\eta) = M_\eta^T(\eta) > 0, \qquad \forall\, \eta \in < R^6 \tag{12}$$

There exists a positive constant m_m and m_M such that $m_m \le k\, M_\eta(\eta)\, k \le m_M$.

Property 2: The matrix $M_\eta - 2C_\eta(\nu,\eta)$ is a skew-symmetric matrix i.e.

$$\begin{aligned} &S^T\left[M_\eta - 2C_\eta(\nu,\eta)\right]S = 0, \\ &\forall\, S \in < R^6, \quad \nu \in < R^6, \quad \eta \in < R^6 \end{aligned} \tag{13}$$

Property 3: The damping matrix $D_\eta(\nu,\eta)$ is strictly positive definite and bounded

$$D_\eta(\nu,\eta) > 0, \quad \forall\, \nu \in < R^6, \quad \eta \in < R^6 \tag{14}$$

There exits a positive constants d_m and d_M such that $d_m < k\, D_\eta(\nu,\eta)\, \mathrm{k} \le d_M$.

The space movement of drones is disturbed by interference in the environment. In general, perturbations are strongly nonlinear and are the addition and multiplication of system modeling equations.

Here we can specify the UAV motion equation with interference and parameter uncertainty

$$\begin{aligned} &\left(M_\eta(\eta) + 4M_\eta(\eta)\right)\ddot{\eta} + \left(C_\eta(\nu,\eta) + 4C_\eta(\nu,\eta)\right)\dot{\eta} \\ &+ \left(D_\eta(\nu,\eta) + 4D_\eta(\nu,\eta)\right)\dot{\eta} + \left(G_\eta(\eta) + 4G_\eta(\eta)\right) \\ &= \tau_\eta + \tau_d \end{aligned} \tag{15}$$

where $\tau_d = \tau_{wave} + \tau_{wind}$ with $\tau_{wave} \in < R^6$ and $\tau_{wind} \in < R^6$ represent external forces. Under parameter uncertainty and external interference in a single expression, then (15) is expressed as follows

$$\widehat{M}_\eta(\eta)\ddot{\eta} + \hat{C}_\eta(v,\eta)\dot{\eta} + \widehat{D}_\eta(v,\eta)\dot{\eta} + \hat{G}_\eta(\eta) = \tau_\eta + \tau_{dis} \quad (16)$$

where

$$\tau_{dis} = \tau_d - 4M_\eta(\eta)\ddot{\eta} + 4C_\eta(\eta)\ddot{\eta} - 4D_\eta(\eta)\ddot{\eta} - 4G_\eta(\eta) \quad (17)$$

Typically, the UAV system includes $\widehat{M}_\eta(\eta)$, $\hat{C}_\eta(v,\eta)$, $\widehat{D}_\eta(v,\eta)$ and $\hat{G}_\eta(\eta)$ approximate values of model parameters. Assuming that the control input vector τ_η is given, it describes the force and torque generated by the dynamics of the actuator, which

$$\dot{\tau}_\eta = R\tau_\eta + \varepsilon \quad (18)$$

The dynamic properties indicate an electromechanical with integrated control, then the final servo does not essentially have a low enough channel to filter out vibrations.

3. Fuzzy Lyapunov function approach

In the first step, we define a model for tracking UAV's flight path in space, which is represented by the following equation in the state space

$$u = \frac{2}{1 + \exp\left(-k_1 e - k_2 \dot{e}\right)} - 1 + u_\delta \quad (19)$$

where, e and $\dot{e}$ are the path after the error and the derivative; k_1 and k_2 are strict normal numbers as surface coefficients; u_δ is the technique used to estimate uncertainty and perturbation, these techniques are from a PI method and perturbation control methods are derived.

The proposed uncertainty estimator is considered a PI control u_{ad} to compensate for structural and non-structural uncertainties, the so-called shock. Based on the estimation of the vector, the system and short-term performance are improved. The development of the estimator is based on the grouped uncertainty vector that is estimated online, rather than depending on the upper limit of the uncertainty. Therefore, it is not necessary to know the uncertainty limit from the beginning, and PI can always compensate for the existing uncertainty. A control law is described as

$$u_{ad} = K_c s + L_{est} \quad (20)$$

$$L_{est} = \Gamma \ s.dt \quad (21)$$

where, Γ is with a positive definition that determines fitness. The robust adaptive expression in (20) is a proportionally integrated PI controller with respect to the sliding surface and is referred to as

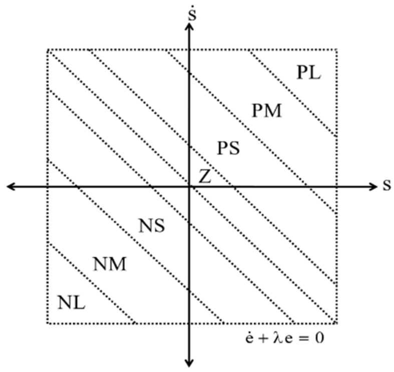

Fig. 1 Rule base structure with adaptuve parameters

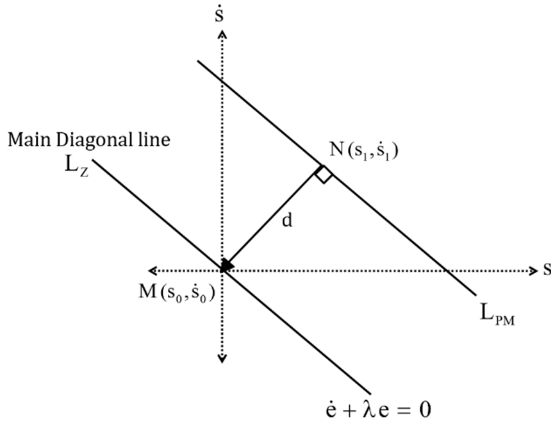

Fig. 2 Signed distance method

$$u_{ad} = K_c s + \Gamma \ s.dt = \delta_p u_{pi} \quad (22)$$

where, δ_p is a diagonal gain and u_{pi} represents the included PI control power, the proportional term makes s close to 0, and the integrated power force converges to zero. The integrated expression plays an important role in ensuring that the state moves forward towards the sliding surface. To improve UAV's track tracking performance, the term "robust adaptive PI" has been replaced by a simplified obscure PI control. As shown in Fig. 1, this structure has the ability to use fuzzy learning and adapt to parameter changes.

When the degree of quantization of the independent variable becomes infinitely small, the limit becomes a straight line as shown in Fig. 2. Also note that the absolute size of the control signal is proportional to the signed distance.

Let $M(s_0, \dot{s}_0)$ be the point of intersection between the diagonal and the vertical line from the working point $N(s_1, \dot{s}_1)$ to obtain distance d. It is clearly seen that the main diagonal can be expressed as a linear function

$$\sigma: \dot{s} + \lambda s = 0 \quad (23)$$

The basic structure of the 2D scale is transformed into a 1D scale using the derived distance d_s. In 1D rule base structure, L_{PL}, L_{PM}, L_{PS}, L_Z, L_{NS}, L_{NM} and L_{NL} are the diagonal lines of 2D rule base table. While, *PL*, *PM*, *PS*, *Z*,

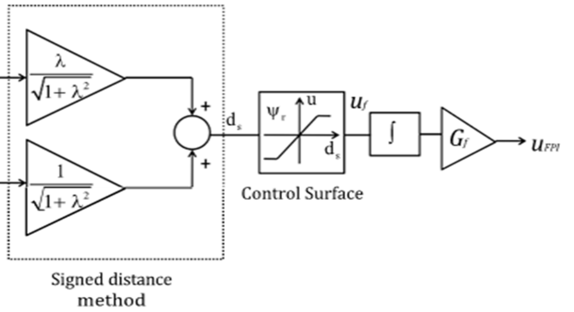

Fig. 3 PI control structure with PWL surface

NS, *NM* and *NL* are the corresponding diagonal output member functions.

The distance d_s is used as an input variable. The main advantage of the method of deleting signatures is that it significantly reduces the rules to be exported. In general, the FLC has two input variables. As shown in Fig. 3, the simplified PI structure can achieve fast calculations due to the lower degree of fuzzification, minimal rule inference, simplified fuzzification process, and piecewise linear control surface (PWL) depending on basic member value.

The PI structure contains a PWL surface, called ψr, which is generated using the asymmetric / symmetric shape of the displayed input / output member function (MF) in Fig. 4. When the distance between the tip of the triangular input MF and the output singleton MF is equal, the discourse universe and this linear surface are obtained. In these cases, the control output obtained from the one-dimensional fuzzy rule-base motor is linear and reported as

$$UFPI = uad = -Gf \int ds.dt \tag{24}$$

The acceleration measurement results used for robotic motion control are as follows

$$\dot{\hat{\tau}}_d = -\Upsilon\hat{\tau}_d + \Upsilon\left[\widehat{M}(\eta)\ddot{\eta} + \widehat{N}_\eta(v,\eta)\dot{\eta} - \tau_\eta\right] \tag{25}$$

where, $\widehat{N}_\eta(v,\eta,\dot{\eta}) = \hat{C}_\eta(v,\eta)\dot{\eta} + \widehat{D}_\eta(v,\eta)\dot{\eta} + \hat{G}_\eta(\eta)$ and *Y* is the observer gain. The main disadvantage in (32) is the need to measure acceleration. Accurate accelerometers are usually not available in robotics. Therefore, a problem arises by differentiating the vehicle speed signal from the measured noise to obtain the acceleration signal and thus using a robust differentiation technique. Therefore, the design of the interference estimator can be changed in a way that does not require acceleration measurement. Therefore

$$s = \hat{\tau}d - \wp(\eta,\dot{\eta}) \tag{26}$$

where, $\wp(\eta,\dot{\eta})$ can be obtained to $Y(\eta,\dot{\eta})$

$$dt\,\wp(\eta,\dot{\eta}) = Y(\eta,\dot{\eta})\widehat{M}(\eta)\ddot{\eta} \tag{27}$$

$$\begin{aligned}\dot{s} = -Y(\eta,\dot{\eta})\hat{\tau}d + Y(\eta,\dot{\eta})\Sigma\widehat{M}(\eta)\ddot{\eta}\\ +\widehat{N}_\eta(v,\eta,\dot{\eta}) - \tau_\eta - \widehat{M}(\eta)\ddot{\eta}\end{aligned} \tag{28}$$

$$\dot{\mathfrak{I}} = \Upsilon(\eta,\dot{\eta})\left[-\left(\mathfrak{I} + \wp(\eta,\dot{\eta})\right) + \widehat{N}\eta(v,\eta,\dot{\eta}) - \tau_\eta\right] \tag{29}$$

based on

$$\dot{\eta} = J(\eta)v \tag{30}$$

Therefore, due to $\widehat{M}(\eta)\ddot{\eta}$, the enhanced perturbation observer does not need to measure acceleration. Therefore, consider the following form

$$\dot{\mathfrak{I}} = -\Upsilon(\eta,\dot{\eta})\mathfrak{I} + \Upsilon(\eta,\dot{\eta})\left[\widehat{N}_\eta(v,\eta,\dot{\eta}) - \tau_\eta - \wp(\eta,\dot{\eta})\right] \tag{31}$$

Here, the error estimator can be specified as

$$\Delta\tau_d = \tau_d - \hat{\tau}_d \tag{32}$$

$$\hat{\tau}_d == +\wp(\eta,\dot{\eta}) \tag{33}$$

where, $\hat{\tau}_d$ is a diagonal gain paramenter of mesurement and η represents the included state control input from the external disturbance, the proportional term makes s close to 0, and the integrated power force converges to zero. Then we have

$$\Delta\dot{\hat{\tau}}_d = \dot{\tau}_d - \dot{\hat{\tau}}_d = \dot{\tau}_d - \left(\dot{\mathfrak{I}} + \dot{\wp}(\eta,\dot{\eta})\right) \tag{34}$$

$$\begin{aligned}\Delta\dot{\hat{\tau}}_d = \dot{\tau}_d - Y(\eta,\dot{\eta}) - s + \widehat{N}_\eta(v,\eta,\dot{\eta})\\ -\tau_\eta - \wp(\eta,\dot{\eta}) - \dot{\wp}(\eta,\dot{\eta})\end{aligned} \tag{35}$$

$$\begin{aligned}\Delta\dot{\hat{\tau}}_d = \dot{\tau}_d - Y(\eta,\dot{\eta})\left(s + \wp(\eta,\dot{\eta})\right)\\ -Y(\eta,\dot{\eta})\widehat{N}_\eta(v,\eta,\dot{\eta}) - \tau_\eta + \widehat{M}(\eta)\ddot{\eta}\end{aligned} \tag{36}$$

Finally, it is derived by

$$\Delta\dot{\hat{\tau}}_d = \dot{\tau}_d - Y(\eta,\dot{\eta})\Delta\tau_d \tag{37}$$

$$Y(\eta,\dot{\eta}) = \Theta - 1\widehat{M}(\eta) - 1 \tag{38}$$

$$\wp(\eta,\dot{\eta}) = \Theta - 1\dot{\eta} \tag{39}$$

$$\hat{\tau}_d = s + \Theta - 1\dot{\eta} \tag{40}$$

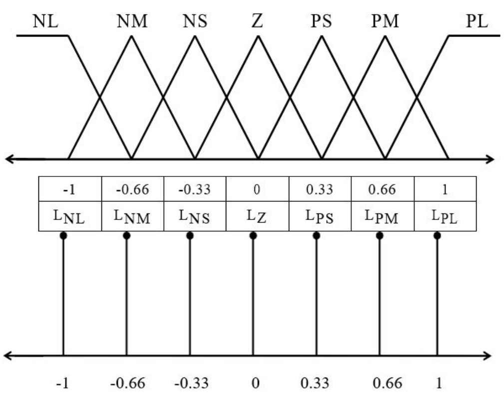

Fig. 4 Input-output membership functions of fuzzy inference engine

For the proposed control law, three control elements have been added to the surface control model S to achieve a robust scheme for UAV orbit space tracking. The first item

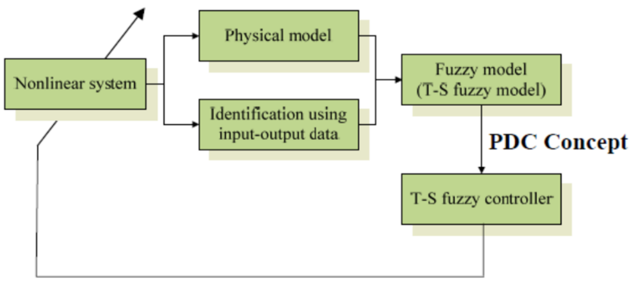

Fig. 5 The structure of controller design for nonlinear systems

is PI control, whose input is used as an uncertainty estimator to estimate the unknown uncertainty that changes over time under various adverse conditions online, and the design of this estimator does not require an upper uncertainty limit. In addition, the introduction of PD compensator can reduce the tracking error in short-term and stable condition. The second term is then used as a non-linear perturbation observer to predict compensation for external perturbations, such as unknown loads, sampling dynamics, and noise measurements.

Due to interference compensation, the non-linear interference observer technology can provide excellent tracking performance without the need for large feedback gains and without measuring acceleration. Finally, the third concept of control, model-based control, can quickly learn the dynamics of the system through the uncertainty created by the uncertainty. The fuzzy model is based on the concept of parallel distribution compensation (PDC), which combines several linear models for an approximate nonlinear system, and the nonlinear controller combines several linear controllers to approximate the nonlinear controller. Therefore, the whole structure of the fuzzy system is shown in Fig. 5. The proposed fuzzy controller divides the same fuzzy set with the fuzzy model in the main part. PDC provides a simple and natural process for solving nonlinear control systems.

Theorem 1: The fuzzy system is stable in the large if there exist common positive definite matrices $P_1,\ P_2,\ \cdots,\ P_r$ such that inequality $\left|\dot{h}_\rho(t)\right| \le \varphi_\rho$ is satisfied and

$$\sum_{\rho=1}^{r} \varphi_\rho P_\rho + \left(A_{j\rightleftarrows} - B_{j\rightleftarrows}K_l\right)P_i + P_i\left(A_{j\rightleftarrows} - B_j K_{l\rightleftarrows}\right) + R + P_i \bar{A}_j R^{-1} \bar{A}_{j\rightleftarrows}^T P_i < 0 \tag{41}$$

where

$$\Delta = \left(A_{j\rightleftarrows} - B_{j\rightleftarrows}K_l\right)P_i + P_i\left(A_{j\rightleftarrows} - B_j K_{l\rightleftarrows}\right), \quad \text{with} \quad P_i = P_i^T > 0, \quad \text{for} \quad i, j, l = 1, 2, \cdots, r \tag{42}$$

4. Examples

Many control systems that implement standard algorithms PID, fuzzy, genetic, neural network, etc. have been developed to achieve the tracking design for aerial systems. Many researchers have developed manual, differential, single pulse, electronic, automatic tracking, left and right, cone and step tracking methods to track the signal source. The performance of standard algorithms and tracking methods used to track signal sources are discussed. In this section, the proposed robust component controller under different types of uncertainties and disturbances, under different conditions, MATLAB/the experimental model with simulations were performed. In fact, the noise signals in position and direction measurement can be traced back to the sensors installed on the vehicle model. In the case of simulation, the meter is expressed as a Gaussian random noise signal, the average value of its linear position and angular direction is 0.01 m, and the standard deviation is 0.01, and it is added to the original state. In addition, the drone starts with an orientation value η0 = [0.8 m 0.4 m 0.4 m 0 0 0].

The bounding matrices are chosen as

$$H_{q1} = \begin{bmatrix} 0.4 & 0.33 \\ 0.012 & 0.414 \end{bmatrix}, \quad H_{q2} = \begin{bmatrix} 0.94 & 0.53 \\ 0.3 & 0.6 \end{bmatrix},$$
$$H_{q3} = \begin{bmatrix} 0.7 & 0.33 \\ 0.162 & 0.384 \end{bmatrix}, \quad \delta_{i\,f\,j} = I.$$

The controller is described to stabilize the nonlinear system

Rule 1: IF $x_1(t)$ is $M_{11}(x_1(t))$ THEN $U(t) = -C_1 X(t)$,

Rule 2: IF $x_1(t)$ is $M_{21}(x_1(t))$ THEN $U(t) = -C_2 X(t)$.

In order to satisfy the stability condition, the choice of an appropriate public positive, particular matrix and control force becomes the biggest problem to be solved. In this case, the solutions obtained can be divided into two categories. This means that designing a fitness feature in the form of a binary operation is an easier way to meet the needs of this application. The fitness function is designed based on the Lyapunov function in accordance with the LMI criterion mode. The logical AND operation is used in the adaptive function to control the solution and generate a binary classification result for the identified solution. The fitness function formula is as follows

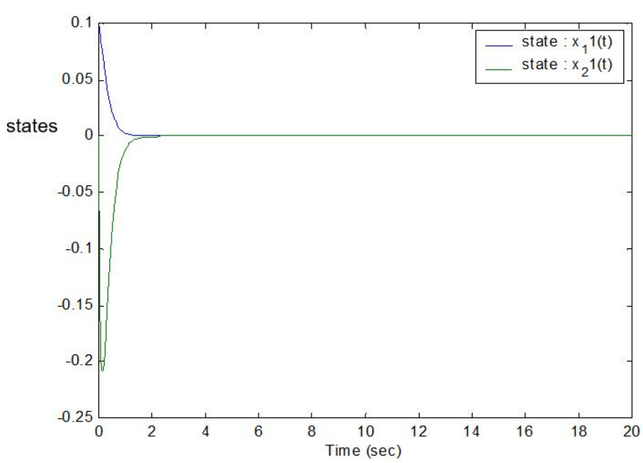

Fig. 6 The state response of fuzzy system 1

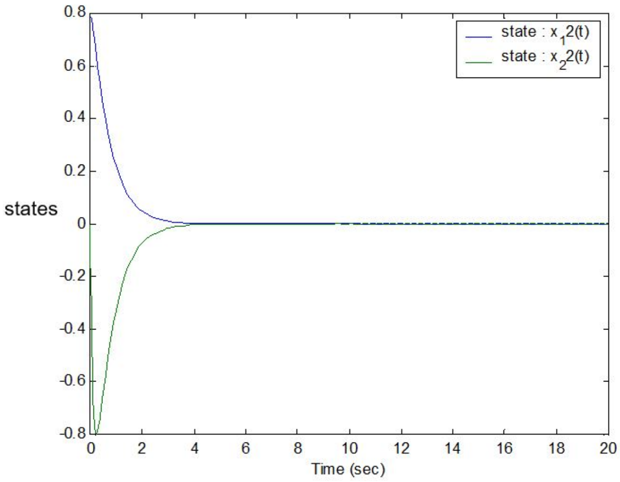

Fig. 7 The state response of fuzzy system 2

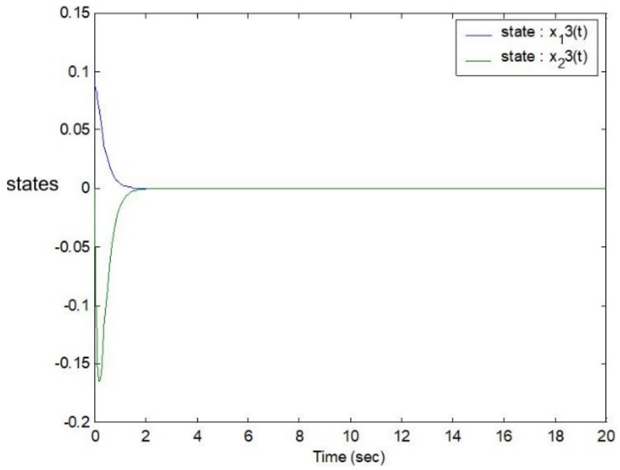

Fig. 8 The state response of fuzzy system 3

Table 1 Control settings of trajectory tracking schemes

Kim *et al*. (2015)	Lakhekar and Waghmare (2017)	Proposed fuzzy Laypunov method
$\Lambda_p = 0.3$	$K_p = 10$	$\Lambda = 0.2$; $\lambda = 0.8$
$K_c = 0.7$	$K_i = 0.01$	$\vartheta_1 = 0.3$; $\vartheta_2 = 0.1$
$K_{in} = 0.9$	$K_d = 60$	$k_p = 10.2$; $k_d = 5.6$
	$\gamma_1 = \gamma_2 = 0.01$	$G_f = 50$

$$P_1 = \begin{bmatrix} 2.771 & 0.309 \\ 0.309 & 0.141 \end{bmatrix}, \quad P_2 = \begin{bmatrix} 2.954 & 0.0292 \\ 0.0292 & 0.0141 \end{bmatrix}, \quad P_3 = \begin{bmatrix} 2.954 & 0.292 \\ 0.292 & 0.141 \end{bmatrix}.$$

Simulation results are illustrated in Figs. 6-8 with arbitrary initial conditions. The regulation is used in Table 1 to generate command signals to reduce tracking errors and follow a non-linear path to reach the desired target position.

5. Conclusions

This paper proposes a composite form of fuzzy adaptive control plan based on a robust observer to track UAV's space path. The proposed method takes advantage of the fuzzy PI uncertainty estimator, non-linear disturbance observer and scheduling control term, and the disadvantages of these methods are mutually corrected. In the various forms of tracking control problems by three-dimensional plane motion, the efficiency of the control technology is proved by means of numerical simulation method. In ariel system control, a signal tracker is required to make the UAV stay in the radiation area and the signal quality can be maintained continuously without any fluctuations. By using this proposed smart tracking design via fuzzy nonlinear criterion, the data link can be further extended, enabling the drone to fly farther without losing the signal. To evaluate the performance of the controller, the proposed controller was compared with other control technologies. This ensures the execution of the control program used to track position and trajectory in the presence of great model uncertainty and external disturbances. The performance of monitoring and control is verified by quantitative analysis.

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