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Enhanced Extended State Observer Based on Trajectory Linearization Control for External and Internal Disturbances

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ABSTRACT: This paper proposes a novel hybrid control framework by combing enhanced extended state observer with trajectory linearization control for air vehicle acceleration tracking problems. First, based on the tracking error dynamics derived by Taylor expansion for the original nonlinear system along the desired trajectory, a feedback linearization-based control law is designed to stabilize a linear time-varying system. To reduce the controller performance sensitivity to uncertainties, with partial model information, an enhanced extended state observer is constructed to estimate the tracking error vector, as well as the uncertainties in an integrated manner. The closed-loop stability of the system under the proposed compound scheme is established. Both numerical simulation studies and an application example of air vehicle acceleration autopilot design demonstrate the feasibility and efficacy of the proposed method.

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1- Introduction

In the last few decades, developments in nonlinear control methods have been made to eliminate perturbations and uncertainties, but each of these controllers (for example trajectory linearization control, gain scheduling controller, backstepping controller, sliding mode controller, etc.) has advantages and disadvantages over each other [1-3]. In order to improve the performance of the mentioned nonlinear controllers, Trajectory Linearization Control (TLC) is used as a new method to control nonlinear systems in the presence of perturbations. In fact, this method can be considered the ideal gain scheduling control. Therefore, due to its specific structure, it provides a certain extent of robust stability and can be capable of rejecting disturbances in nature. As for inevitable disturbances, theoretical and practical investigations show that a basic TLC frame may be degraded by slightly large disturbances [4, 5]. To enhance system robustness, one natural idea is to design observers for estimating and compensating for the disturbances. Such observers can be based on fuzzy logic or neural network. However, online fuzzy or neural network estimation is always time-consuming. One can see that the disturbance rejection problem for TLC has been converted into parameter estimation by utilizing NN and fuzzy logic. Therefore, substantial efforts have centered around the following aspects: (1) the construction of neural network structure and fuzzy logic rules; and (2) the stability discussion of the compound system based on the estimated uncertainties. Extended State Observer (ESO), as the centerpiece of the Active Disturbance Rejection Control (ADRC) technique, is a great solution to meet this fast computation requirement, which takes all internal and external disturbances as an extended state [6, 7]

An observer named Enhanced Extended State Observer (EESO) is proposed to distinguish and estimate the unfavorable disturbance by just introducing the reference signal into the feedback term[1]. Besides supplying satisfactory robustness, the proposed EESO Based Control (EESOBC) that combines EESO with TLC strategy, is able to force the controlled output to track arbitrary reference signals. Central to this novel design framework is the ability of EESO to estimate both the internal dynamics and external disturbances of the considered system in real time.

2- Methodology

2- 1- Configuration of trajectory linearization control based enhanced extended state observer

As shown in Fig. 1, Trajectory Linearization Control Based Enhanced Extended State Observer (TLC-EESO) design method consists of three parts. One is

the forward loop is designed by the use of the nonlinear

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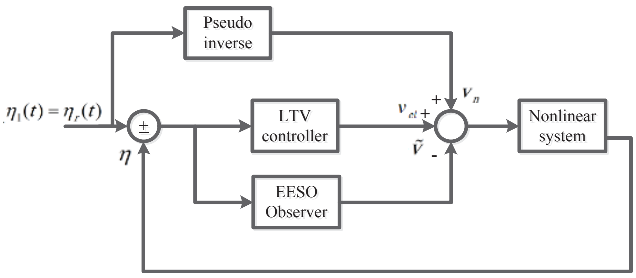

Fig. 1. Configuration of trajectory linearization control based enhanced extended state observer (TLC-EESO)

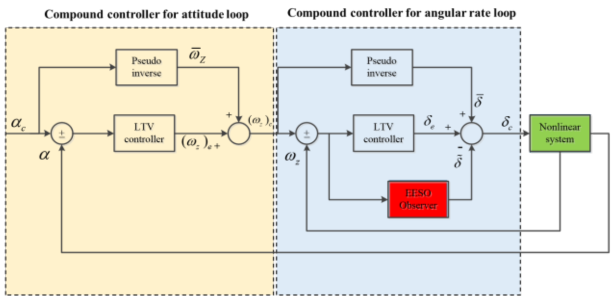

Fig. 2. Configuration of TLC-EESO for air vehicle

dynamic inverse method, which changes the trajectory tracking problem into error adjustment problems. The second part is the state feedback loop designed by the use of linear varying system Parallel-Differential (PD) spectral theory, which ensures the robustness of the system with model errors. Another part is the EESO observer.

2- 2- Trajectory linearization control based enhanced extended state observer design for air vehicles in the presence of multiple uncertainties

A generic longitudinal air vehicle nonlinear dynamics model is described as

$$\begin{cases} \dot{V} = \dfrac{\rho V^2 S}{2m}\left(C_A \cos\alpha - C_N \sin\alpha\right) - g\sin\gamma \\ \dot{\alpha} = -\dfrac{\rho V S}{2m}\left(C_A \sin\alpha + C_N \cos\alpha\right) + \omega_z + \dfrac{g}{V}\cos\gamma \\ \dot{\omega}_z = \dfrac{\rho V^2 S D}{2 I_y} C_M \\ \dot{\gamma} = \dfrac{\rho V S}{2m}\left(C_A \sin\alpha + C_N \cos\alpha\right) - \dfrac{g}{V}\cos\gamma \end{cases} \quad (1)$$

Fig. 2 shows the structure of the proposed novel attitude control design for an air vehicle with multiple disturbances. By using the TLC-EESO method for air vehicle system, the present control system can be separated into an attitude loop and angular rate loop. The angular rate loop is accounted for regulating the angular rate by acting on deflection angles whereas the attitude loop is employed to track the reference attitude command α_c by considering the reference angular rate command $(\omega_z)_c$ as the input control. In a view of disturbance rejection and high accuracy guaranteed, a similar structure is applied in each loop, where the estimation error provided by EESO is constructed. Finally, the compound controller is implemented by integrating with the nominal controller for an open-loop system and observed based EESO controller in each loop.

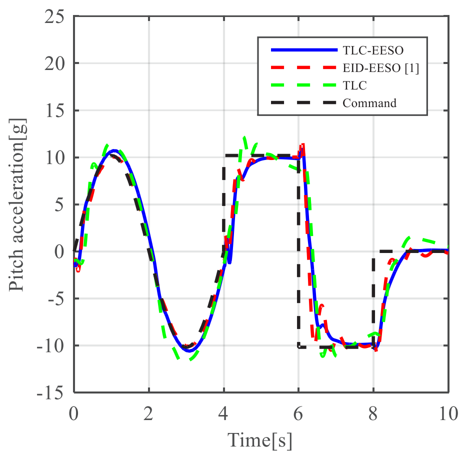

Fig. 3. histories in the presence of 50% uncertainties in aerodynamic coefficients and 10% uncertainties in structural parameters

3- Results and Discussion

To make the work more challenging, severe parametric perturbations are considered in this case, namely −10% uncertainties in structural parameters (including m, S, D, I_y, and ω_a), +50% uncertainties in aerodynamic coefficients *CA* and *CN*, as well as −50% uncertainty in pitch moment coefficient *CM*.

The results depicted in Fig. 3 indicate that given parametric perturbations make almost no difference to the proposed TLC-EESO autopilot, but excite severe oscillations in terms of the response curve of the EID-EESO when tracking the square wave command. Moreover, owing to its superiority of actively rejecting disturbances, the TLC-EESO autopilot can even tolerate up to ±75% aerodynamic coefficient perturbations, while in the same case, the acceleration under the EID-EESO autopilot goes unstable, as shown in Fig. 4

4- Conclusions

In this paper, a novel composite control scheme combined with the advantages of TLC and EESO observer is developed to address the attitude tracking problem of the air vehicle.

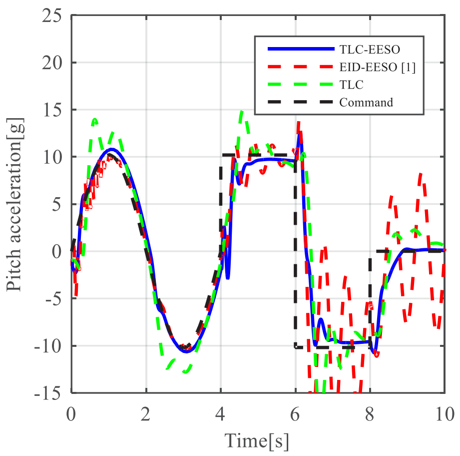

Fig. 4. Acceleration histories in the presence of 75% uncertainties in aerodynamic coefficients and 10% uncertainties in structural parameters

The Bounded-Input, Bounded-Output (BIBO) stability and ultimate tracking error bound are rigorously analyzed based on the proposed robust TLC's specific structure. It is proven that the ultimate upper bound of closed-loop tracking error monotonously decreases with the controller's and EESO's bandwidths. The simulations and comparative study are carried out to demonstrate that the proposed TLC-EESO method can obtain better tracking performance for tracking attitude command systems with internal and external perturbation.

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