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Comments on “Controller design for rigid spacecraft attitude tracking with actuator saturation”

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ABSTRACT

In 2013, Lu, Xia and Fu proposed three robust controllers for rigid spacecraft attitude tracking with inertia uncertainties, external disturbances and actuator saturations. In this comment, we point out several flaws occurred through the paper, leading to the ineffectiveness of the proposed controllers.

1. Introduction

The above paper [1] investigated the robust tracking problem of rigid spacecraft in the presence of inertia uncertainties, external disturbances and actuator saturations. Unfortunately, several key claims in the proofs of theorems are erroneous, leading to the untenable main results in the paper.

2. Errors

2.1. Error of the adaptive sliding mode control design under actuator saturations

In the Section 3 of [1], an adaptive sliding mode control design is developed for asymptotic tracking of rigid spacecraft under actuator saturations. The saturation function $sat(u)$ is given by [1, Eqs. (12) and (13)]

$$sat(u) = \Theta(u) \cdot u \tag{1}$$

with $\Theta(u) = diag[\Theta_1(u),\ \Theta_2(u),\ \Theta_3(u)]$ and $\Theta_i(u)$ is defined by

$$\Theta_i(u) = \begin{cases} 1, & |u_i| \le u_{mi} \\ u_{mi}/u_i \cdot sign(u_i), & otherwise \end{cases} \tag{2}$$

An key claim on $\Theta(u)$ is made in the second line below Eq. (13) of [1] as follows: There exists a constant δ satisfying

$$0 < \delta \le \min(\Theta_i(u)) \le 1 \tag{3}$$

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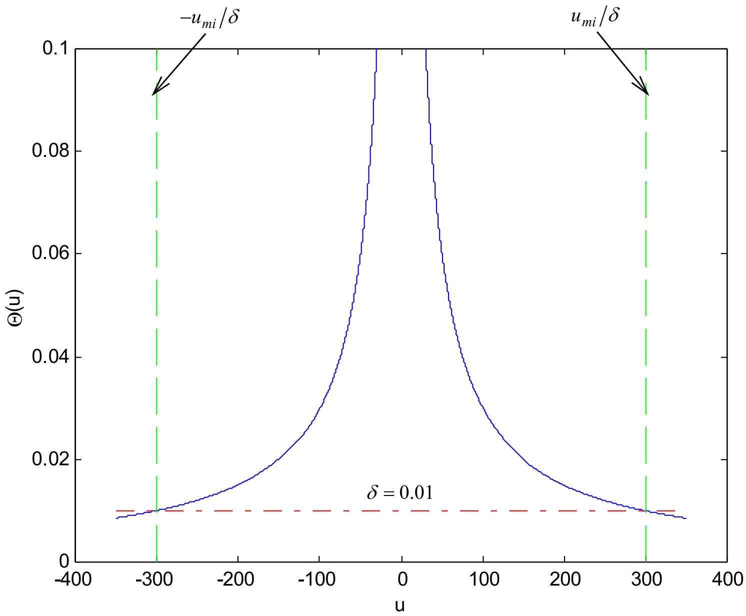

Fig. 1. Plot of $\Theta(u)$ with u ($u_{mi} = 3$ and $\delta = 0.01$).

Unfortunately, this claim is erroneous. In fact, $\min(\Theta_i(u))$ does not exist at all. As a counterexample, let $\delta = \varepsilon$ and ε is an arbitrarily small positive constant. It is clear that Eq. (3) holds only for the case of $|u_i| \le u_{mi}/\varepsilon$. For $|u_i| > u_{mi}/\varepsilon$, $\min(\Theta_i(u)) < \varepsilon$, i.e. $\min(\Theta_i(u)) < \delta$; and hence Eq. (3) does not hold. In other words, to ensure that Eq. (3) hold, δ is not a positive constant but a positive variable that relies heavily on u_i. The relationship of $\Theta(u)$ with u is illustrated in Fig. 1. As we see, if the designed control input u is bounded, then inequality (3) holds true. Unfortunately, from the control design given by (14) and (15) in Theorem 1 of [1], it is clear that u is not bounded as u_{s1} is unbounded. Hence the claim that δ is a positive constant is incorrect.

Since δ is not a positive constant, an additional term $-\sum_{i=1}^{3}[\frac{1}{p_i\delta}(c_i - \delta\hat{c}_i)\dot{\delta}\hat{c}_i]$ should be added in the equality of the time derivative of the Lyapunov function candidate given after Eq. (19) of [1]. As a result, Eq. (20) of [1] is not guaranteed to hold. This leads to the erroneousness of Theorem 1 of [1].

2.2. Errors of the controller design with observer

In the Section 4 of [1], an ESO-based controller is proposed in Theorem 2. The proof of Theorem 2 in [1] is based on the convergence of the ESO. It is known from [2,3] that, to ensure the convergence of the ESO, the unknown function to be estimated by the ESO should be continuously differentiable with respect to their variables as well as be bounded in a certain sense (see Assumption (H1) of [2] for details). As for the system given by Eq. (33) of [1] to be estimated by the ESO, this implies that function $g(t)$ should meet the above continuously differentiable and bounded conditions. From Eq. (33) of [1], it is clear that function $g(t)$ is the time derivative of the uncertain function $\tilde{G}$. In light of Eq. (31) of [1], it is clear that function $\tilde{G}$ includes a term $\Delta JJ^{-1}u$. These facts imply that the control input u should be C^2 function such that the functions $g(t)$ and $\tilde{G}$ meet the continuously differentiable condition required by ESO. Unfortunately, from the control design given by Eq. (39) in Theorem 2 of [1], it is clear that u does not a C^2 function due to it involves the discontinuous signum term $sign(\tilde{S})$and non-smooth term $sign^r(\tilde{S})$. Therefore, on the basis of the work presented in [2,3] and the above discussion, the convergence of the used ESO of [1] is not guaranteed to hold; and hence, the proof of Theorem 2 of [1] is incorrect.

2.3. Errors of the controller design with observer under control input saturations

In the Section 5 of [1], an ESO-based sliding mode control is presented for bounded tracking of spacecraft under control input saturations. From the control law defined by Eq. (49) in Theorem 3 of [1], it is clear that u_{eso} also does not satisfy the continuously differentiable condition of ESO. That is, the continuously differentiable condition of the unknown function $\bar{G}$ does not meet. As a consequence, by the work presented in [2,3] and the previous discussion, Theorem 3 in [1] is also untenable.