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Innovative Integral Observer Improves Disturbance Observation in Uncertain Systems: Experimental Validation in Quadrotor UAV Attitude Control

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Introduction

Disturbances in industrial control systems impact their robustness. Several disturbance observers (DOs) proposed, such as linear extended state observer (LESO), nonlinear disturbance observer (NDO) are low-type Dos except the compensation function observer (CFO) improving the estimation accuracy. However, research on quantifying disturbance sensitivity in the time-frequency domain and its practical application in control tuning is lacking. Experimental validation of DO performance is insufficient.

Mathematical Formulas

$$\begin{aligned}\dot{z}_1 &= z_2,\\ &\vdots\\ \dot{z}_n &= L\boldsymbol{e} + z_{n+1} + bu,\\ \dot{z}_{n+1} &= \lambda L\boldsymbol{e},\\ \hat{f} &= L\boldsymbol{e} + z_{n+1}.\end{aligned} \tag{1}$$

$$G_{\mathrm{CFO}}^{D}(s) = \frac{s^{n+1}}{(s+a)(s+ba)^{n}}. \tag{2}$$

Research Questions

1) What methods can be employed to enhance the type of estimable disturbance in observers?
2) How to investigate the sensitivity of estimated disturbances in the frequency domain of DOs?
3) How to establish a quantitatively unified comparison standard for DOBCs?

Figure

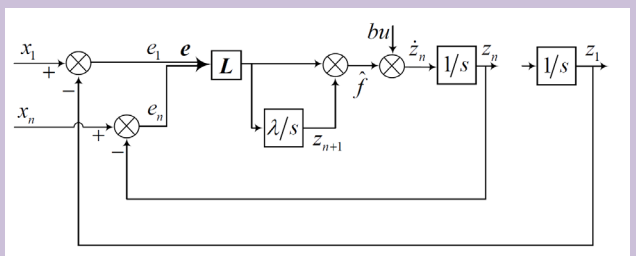

FIGURE 1. Block diagram of the $(n+1)^{\mathrm{th}}$-order integral CFO

Methodologies

One of the most well-known observers for estimating disturbances is the extended state observer (ESO). This study proposes a novel observer, referred to as the CFO, to improve the type and broaden the bandwidth of estimable disturbances. Moreover, the control strategy based on CFO offers benefits in enhancing disturbance rejection performance.

Table

TABLE 1. 99% Accuracy bandwidths of 2^{nd}, 3^{rd}, and 4^{th} orders CFO, LESO, and IESO

DOs	CFO	IESO	RATIO	LESO	RATIO
2^{nd}	0.0834	0.0834	same	0.00358	23
3^{rd}	0.274	0.0639	4.3	0.00318	8.6
4^{th}	0.375	0.0414	9	0.00238	157

Conclusion

The proposed integral compensation function observer (CFO) overcomes limitations of the linear extended state observer (LESO). Investigation of disturbance sensitivity transfer function (DSTF) in the time-frequency domain reveals CFO's enhancement in type of estimable disturbance and estimation accuracy compared to LESO and improved ESO (IESO). Experimental results demonstrate CFO-based control is superior disturbance rejection performance (DRP) over IESO/LESO-based control.