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An error-based observer improved by the repetitive control strategy for electro-optical tracking systems

Key words: Disturbance suppression; Error-based observer; Repetitive control; Electro-optical tracking system; Specific frequency point

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Electro-optical tracking system

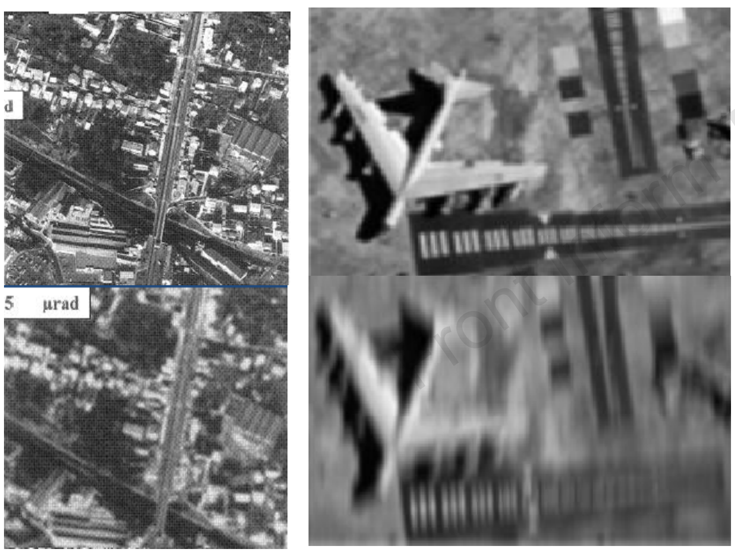
- The electro-optical tracking system refers to a comprehensive optical instrument that integrates mechanical structures, electronic power, control system, and other structures. It has been widely used in biomedicine, aerospace, astronomical observations, quantum computing, microstructure characterization, long-distance information transmission, and other fields [1-4].






Motivation

- As the application environments for electro-optical tracking systems grow increasingly complex, the variety and complexity of disturbances encountered are escalating. In the context of shipboard and airborne electro-optical systems, encountering multiple sets of harmonic disturbances with different frequencies or non-periodic relationships of disturbance signals is quite common.



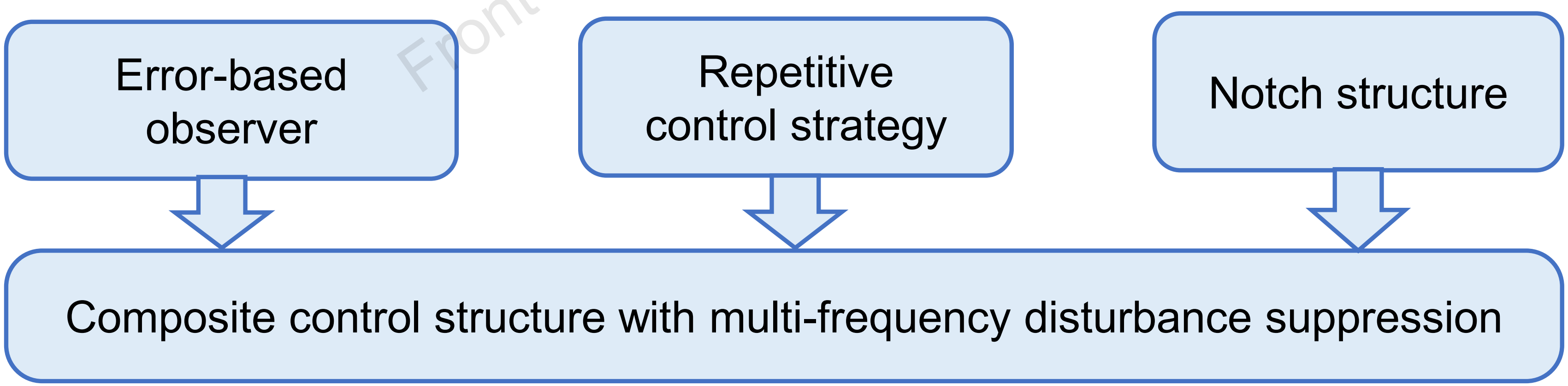
$$d(t) = \sum_{i=1}^{n} d_{\mathrm{P}i}(t) + \sum_{j=1}^{m} d_{\mathrm{A}j}(t)$$

$$\sum_{i=1}^{n} d_{\mathrm{P}i}(t) = \sum_{i=1}^{n} A_i \sin(\omega_i t + \varphi_i)$$

Method

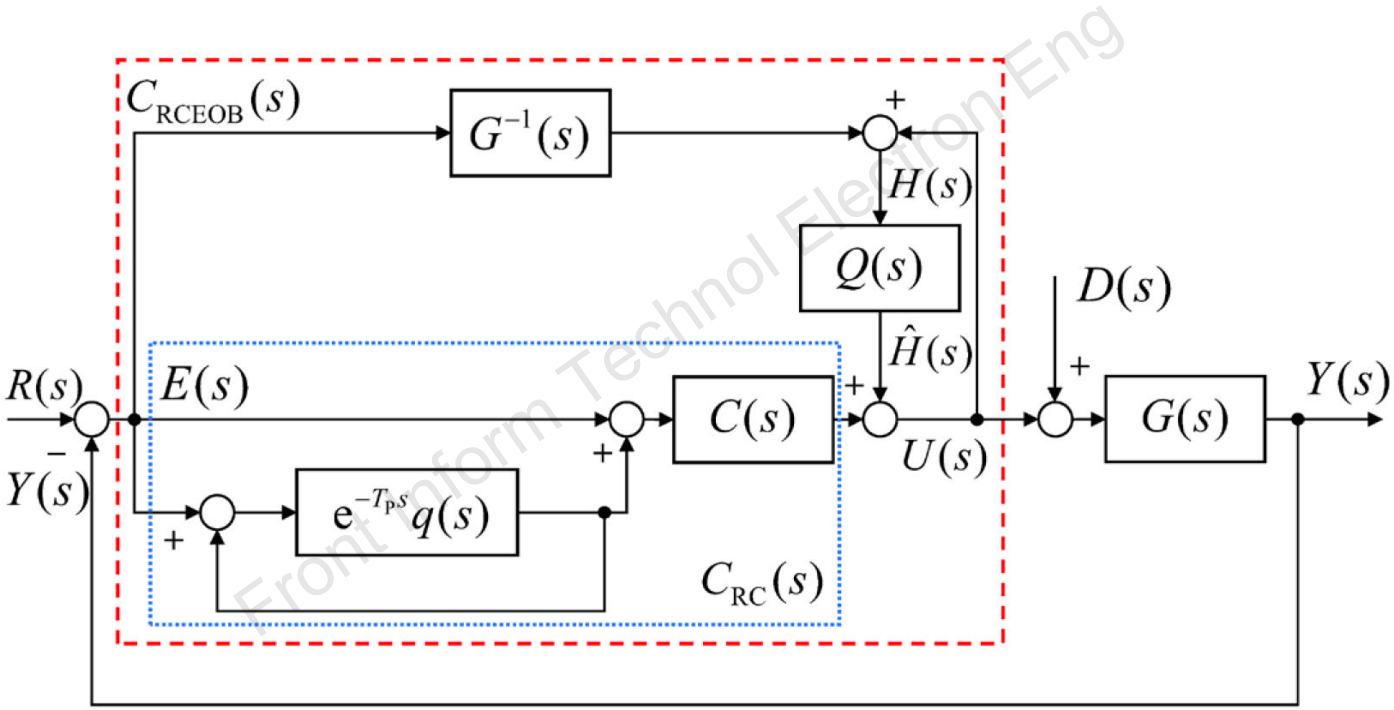
- To achieve more complex disturbance suppression, it is essential to establish a control structure that can not only ensure the basic stability of control performance across the entire frequency spectrum, but also offer flexibility in selecting disturbance suppression structures at multiple frequencies.

- This paper introduces an error-based observer structure grounded in a repetitive control strategy. This structure is designed to meet the stability requirements of the control system while effectively suppressing periodic disturbances.



Method

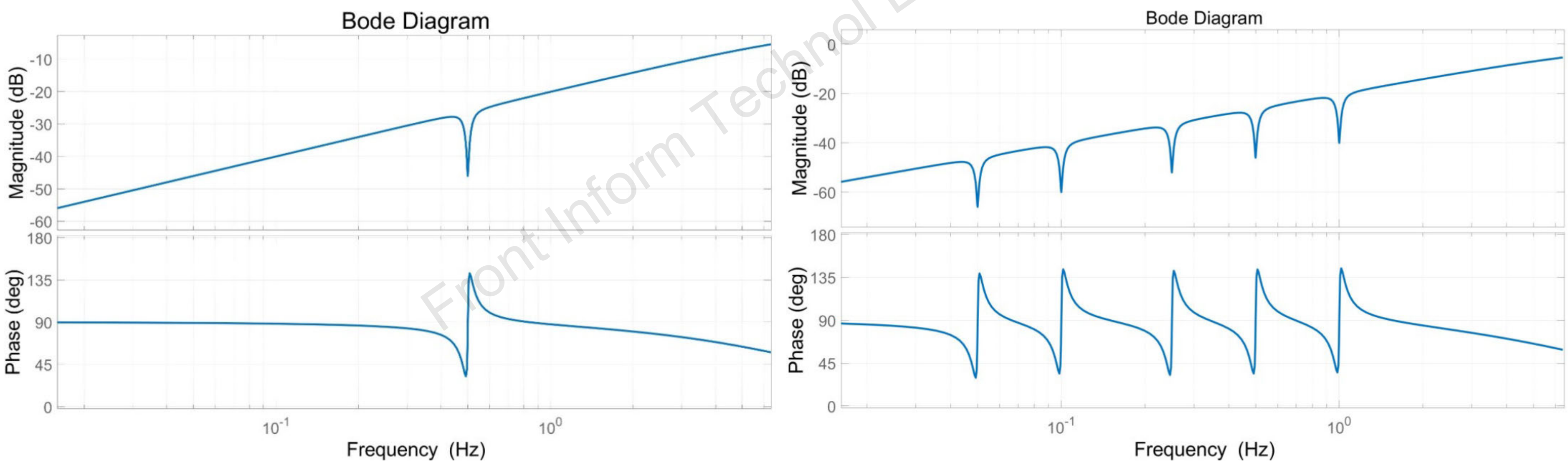
- Structure of the proposed error-based observer improved by a repetitive control strategy



1) Notch at discrete frequency points

- The notch effect at discrete frequency points in the proposed error-based observer improved by a repetitive control strategy (RCEOB) is realized by the improved structure of $Q_N(s)$.

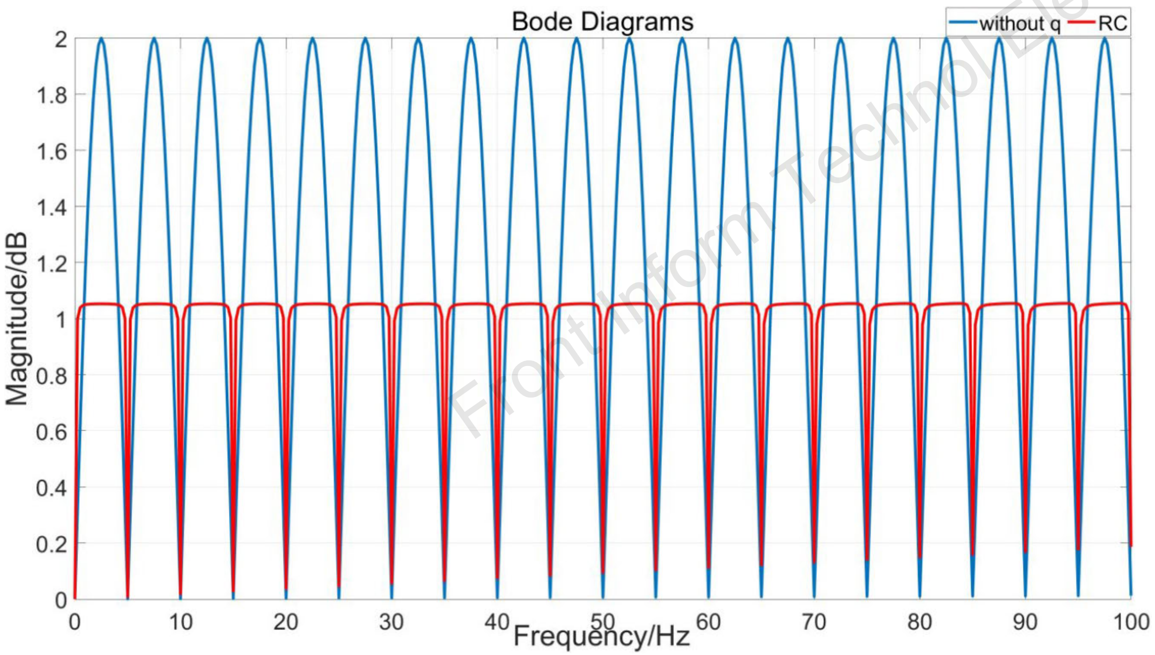
$$Q_{\mathrm{N}}(s) = 1 - \prod_{i=1}^{a} \frac{s^2 + \eta_i \omega_i s + \omega_i^2}{s^2 + \alpha_i \eta_i \omega_i s + \omega_i^2} \left(1 - q_{\mathrm{LPF}}(s)\right)$$



Complementary sensitivity function of $Q_N(s)$ with single-notch and multi-notch structures

2) Repetitive controller

- By using this structure, the closed-loop controller can achieve high performance and suppress harmonic signal disturbance at the repetition frequency.
- To suppress the waterbed effect, the *q*(*s*) in the repetitive controller is improved.



Sensitivity function of the improved repetitive controller

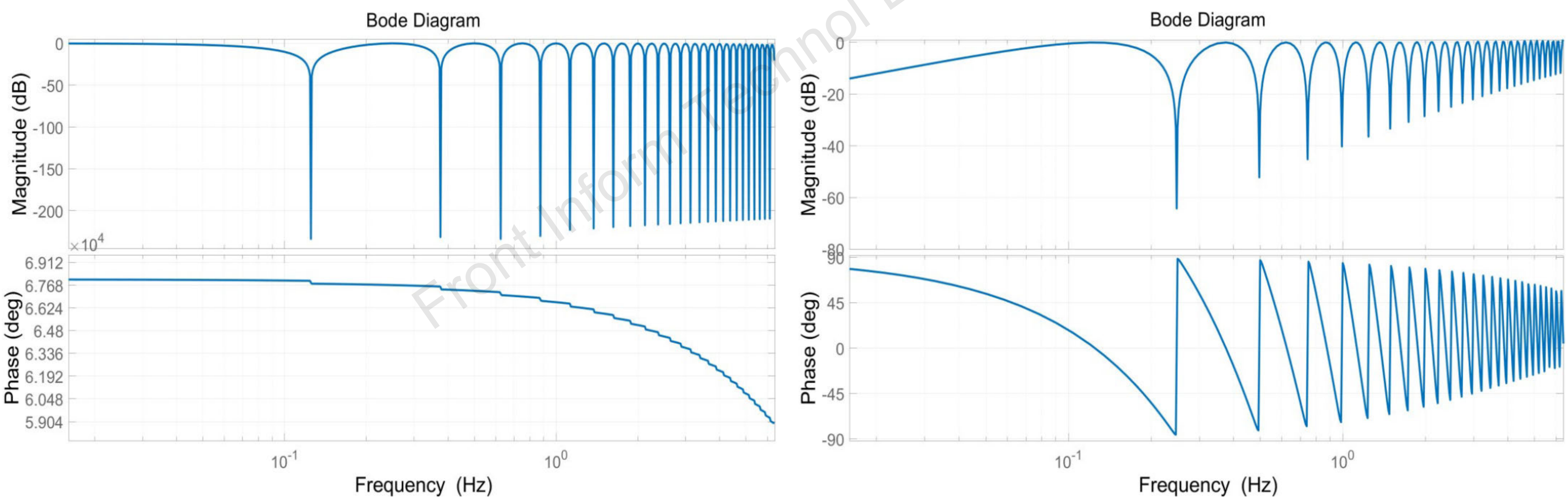
$$C_{\mathrm{RC}} = \frac{C(s)}{1 - \mathrm{e}^{-T_{\mathrm{P}}s} q(s)}$$

$$q_{\mathrm{new}}(s) = \frac{kq(s)}{1 - (1-k)\mathrm{e}^{-T_{\mathrm{P}}s}}$$

3) Filter improved by the repetitive control strategy

- By introducing the repetitive control strategy into the filter structure, we try to expand the disturbance suppression ability of the control structure in the above working environment.

$$Q_{\mathrm{RC}}(s)=[1-\beta(1-\mathrm{e}^{-T_{\mathrm{P}}'s})]\cdot q_{\mathrm{LPF}}(s)$$

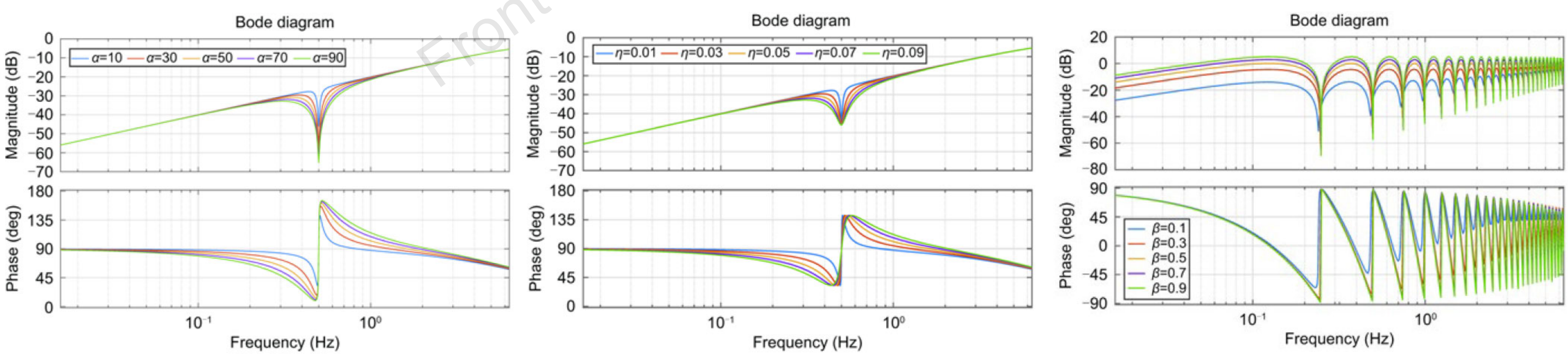


Sensitivity function curve and complementary sensitivity function curve of $Q_{\mathrm{RC}}(s)$

4) Parameter selection for the multi-notch structure

- We list all the adjustable parameters in the $q(s)$ and two $Q(s)$ structures, and then give the reference value of each parameter.

Source	Parameter	Value
$C_{RC}(s)$	k	0.1
	T_P	0.2 s
$Q_N(s)$	α_i	10
	η_i	0.01
	ω_i	2 Hz
$Q_{RC}(s)$	β	0.5
	T_P'	1 s



Changes of the complementary sensitivity function with different values of parameters

Conclusions

- In this paper, a multi-notch controller structure (RCEOB) with multiple selectable parameters is proposed to deal with periodic disturbance in the process of the electro-optical tracking system, especially multi-periodic harmonics and narrow-band peak disturbances, which are difficult to suppress by the existing disturbance suppression methods.

- The experiments validate the effectiveness of the composite controller structure of RCEOB through the parameter design given in the theoretical analysis, and different filter structures are implemented, showing that the given multi-notch structure is feasible. RCEOB does improve the disturbance suppression ability of the system, which proves that the control method proposed in this work can improve the operating performance of the electro-optical system under multi-period and discrete point disturbance conditions.

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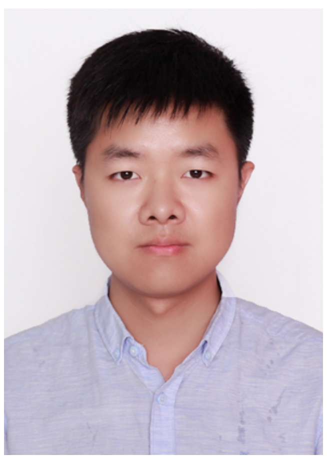

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