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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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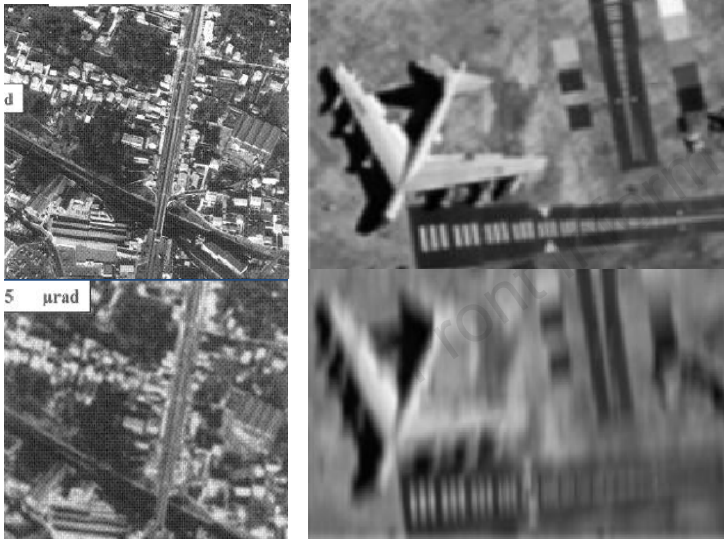
Electro-optical tracking system

- ❑ 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.

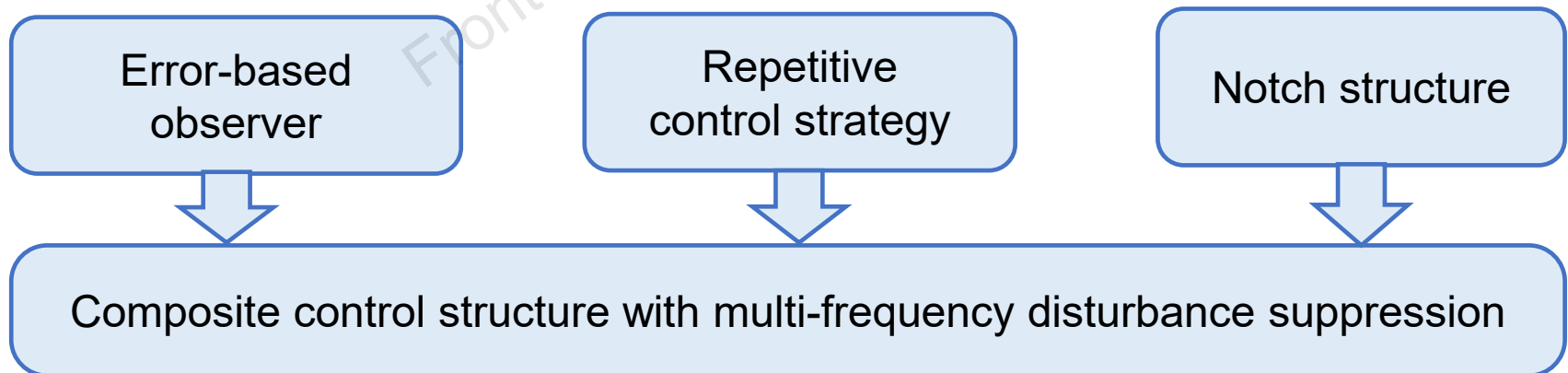


$$d(t) = \sum_{i=1}^n d_{Pi}(t) + \sum_{j=1}^m d_{Aj}(t)$$

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

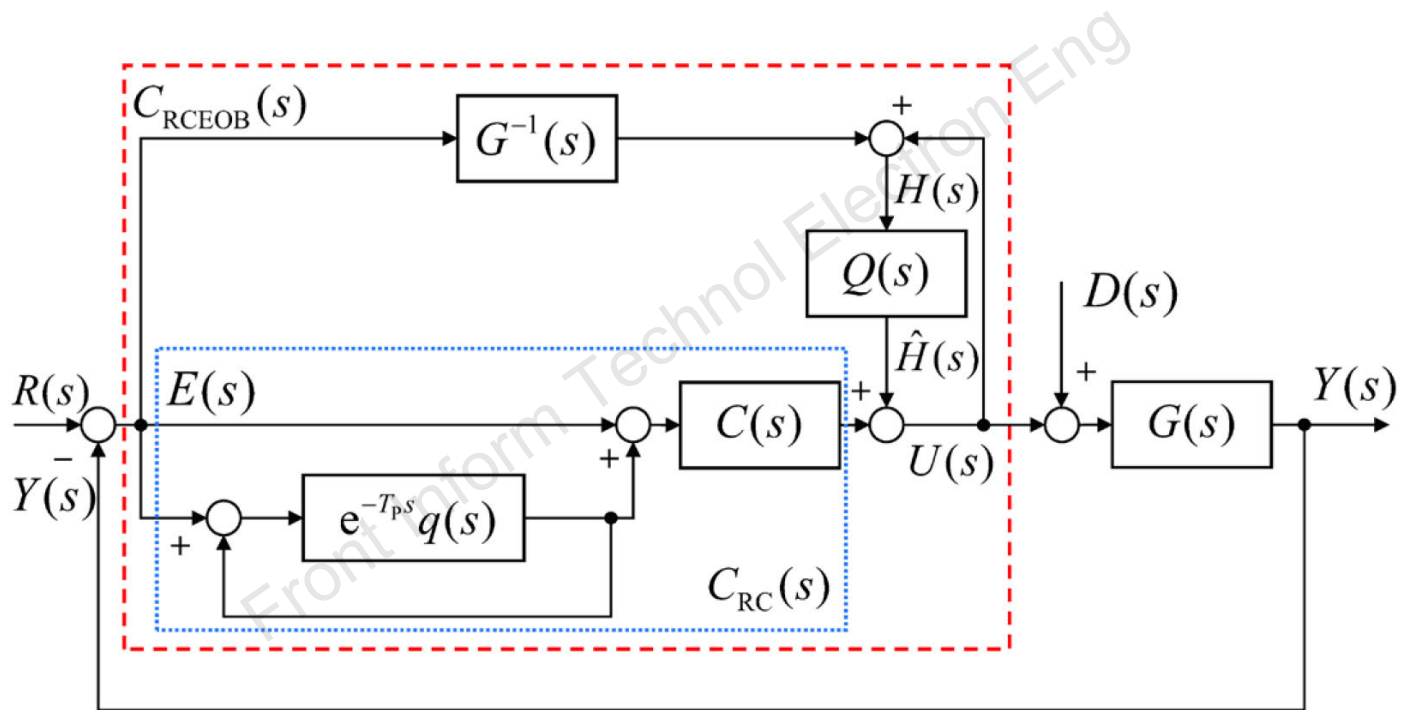
Method

- ❑ 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

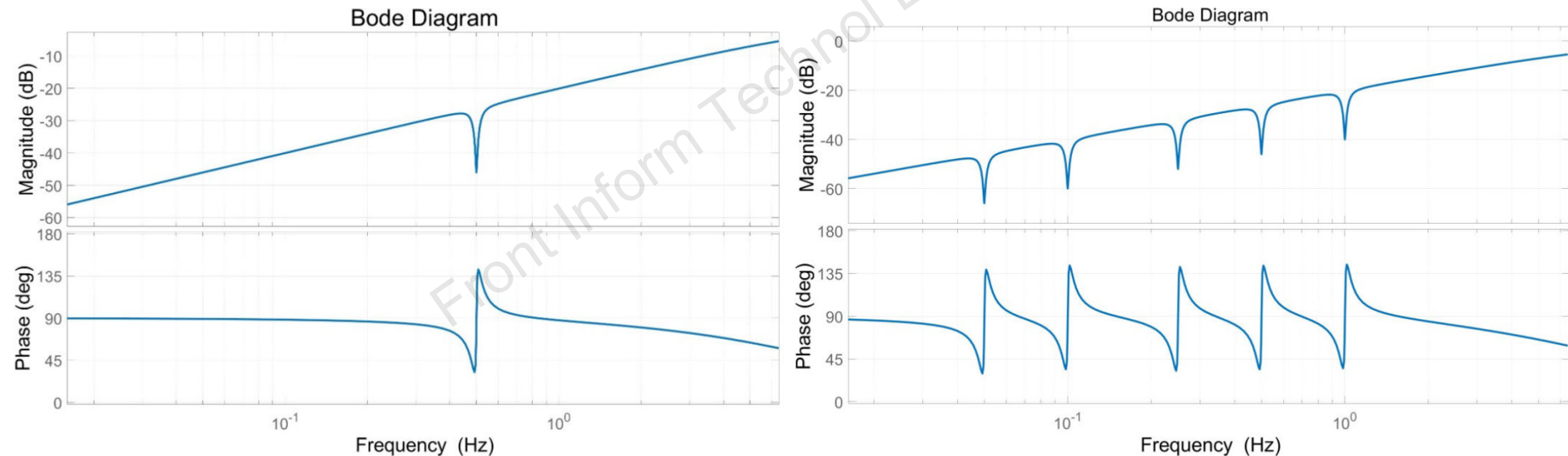
- ❑ Structure of the proposed error-based observer improved by a repetitive control strategy



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 $Q_N(s)$.

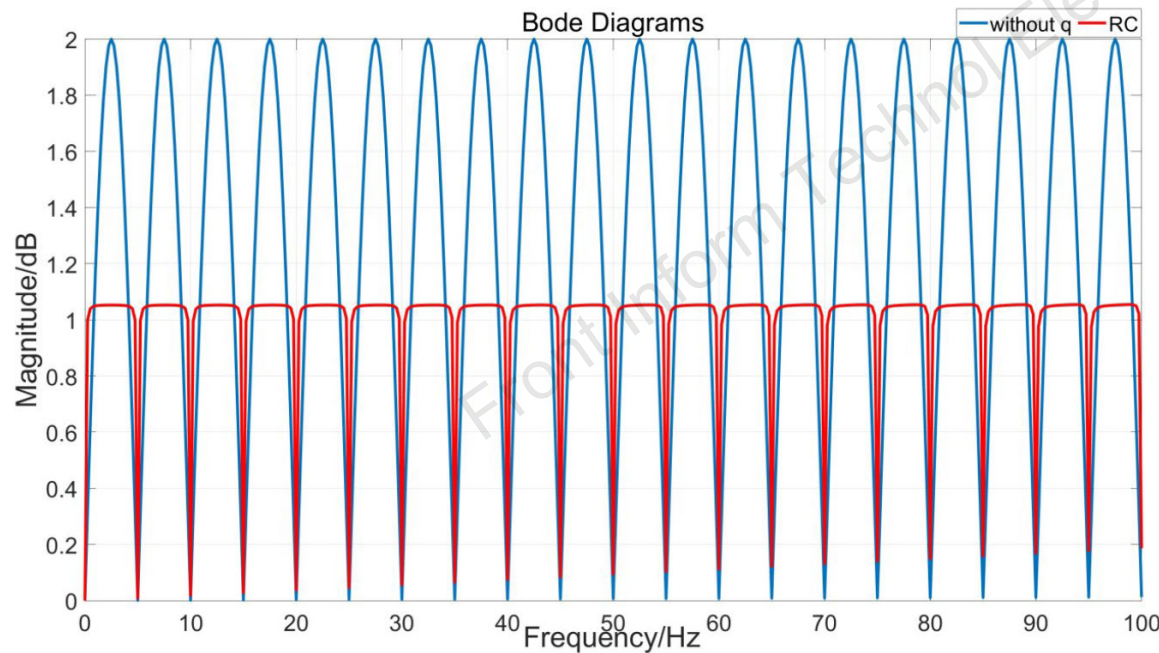
$$Q_N(s) = 1 - \prod_{i=1}^a \frac{s^2 + \eta_i \omega_i s + \omega_i^2}{s^2 + \alpha_i \eta_i \omega_i s + \omega_i^2} (1 - q_{\text{LPF}}(s))$$



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

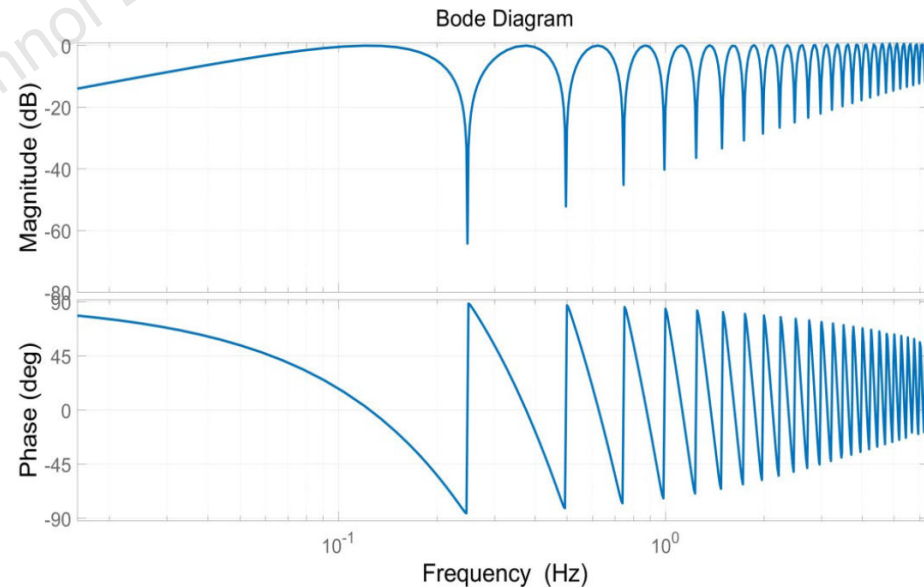
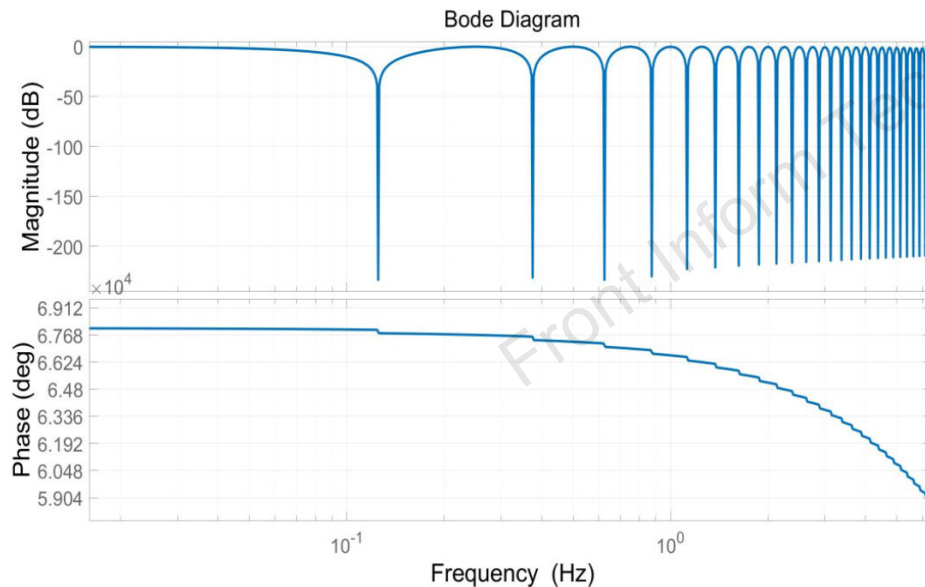
$$C_{RC} = \frac{C(s)}{1 - e^{-T_p s} q(s)}$$

$$q_{\text{new}}(s) = \frac{kq(s)}{1 - (1 - k)e^{-T_p s}}$$

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.

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

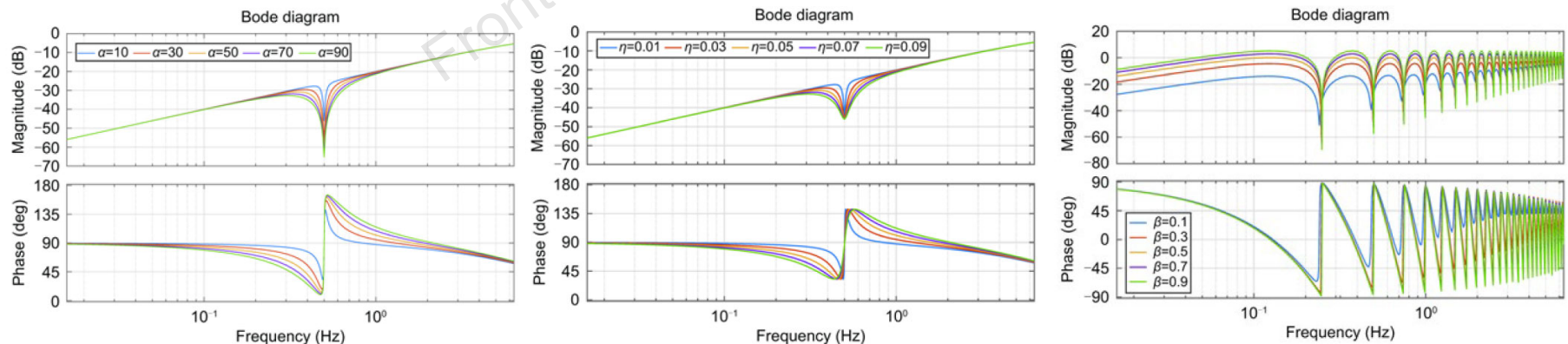


Sensitivity function curve and complementary sensitivity function curve of $Q_{RC}(s)$

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

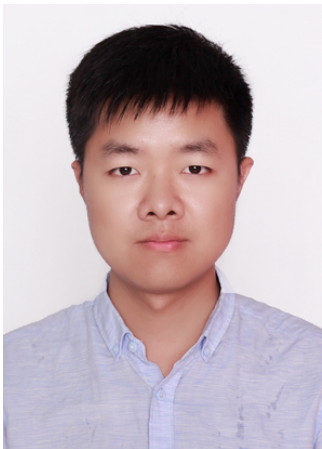
- ❑ In this paper, a **multi-notch controller structure** (RCEOB) with multiple selectable parameters is proposed to deal with periodic disturbance in the process of the electro-optical tracking system, especially **multi-periodic harmonics and narrow-band peak disturbances**, which are difficult to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

References

- [1] Beaulieu-Laroche, L., Brown, N. J., Hansen, M., et al., 2021. Allometric rules for mammalian cortical layer 5 neuron biophysics. *Nature*, 600(7888):274-278.
- [2] Berkefeld, T., Soltau, D., Schmidt, D., et al., 2010. Adaptive optics development at the German solar telescopes. *Applied Optics*, 49(31):G155-G166.
- [3] Madsen, L. S., Laudenbach, F., Askarani, M. F., et al., 2022. Quantum computational advantage with a programmable photonic processor. *Nature*, 606(7912):75-81.
- [4] Kalita, A., Mrozek-McCourt, M., et al., 2023. Microstructure and crystal order during freezing of supercooled water drops. *Nature*, 620(7974):557-561.



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