# WIP: 디지털 트윈 응용을 위한 다중 센서 참조 기반 적응 필터링을 이용한 PMDC 모터 베어링 고장 분류

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# WIP: Bearing Fault Classification in PMDC Motors Using Multi-Sensor Reference-Based Adaptive Filtering for Digital Twin Application

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Abstract

Bearing fault diagnosis in permanent-magnet DC (PMDC) motor drives remains unreliable under variable load when amplitude-dominated vibration features are employed. This study presents a reference-conditioned envelope-spectrum framework in which a gearbox-mounted vibration signal is used exclusively to contextualize motor-side measurements. Motor and reference signals are mapped into a normalized envelope-spectrum domain, and cross-reference envelope attributes (CREA) are derived to support reference-conditioned feature representation. Experiments are conducted on a PMDC motor–gearbox dynamometer under stepped torque conditions with seeded bearing faults. Preliminary analyses indicate improved feature stability compared to motor-only baselines. Owing to its low-dimensional and reference-aligned formulation, the proposed framework is suitable for lightweight condition monitoring and integration within digital twin-oriented monitoring architectures. Ongoing work includes run-level aggregation, ablation studies, and explainability analysis under variable load.

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## Ⅰ. Introduction

Rolling element bearings are among the most frequent failure points in rotating machinery, motivating extensive vibration-based condition monitoring research [1]. Envelope analysis is widely used to extract bearing fault signatures under steady operating conditions [2]; however, in brushed PMDC motor systems, diagnostic reliability deteriorates significantly. Torque variation introduces non-stationary operating regimes [3], while electromechanical commutation generates brush arcing and switching harmonics that interact with mechanical vibration [4]. As a result, amplitude-driven indicators such as RMS and kurtosis often reflect operating condition changes rather than bearing health [5].

To address this limitation, this work exploits a physical asymmetry inherent to PMDC drivetrains. A gearbox-mounted vibration sensor is mechanically coupled to the motor while remaining electrically isolated from commutation phenomena. Rather than contributing independent features to the classifier, this signal is used solely as a reference baseline to condition interpretation of the motor-side envelope spectrum. CREA are employed to express motor vibration characteristics relative to this reference, with the aim of improving diagnostic stability under variable load without introducing fusion-induced leakage or amplitude dominance. From a digital twin perspective, this reference-conditioned representation functions as a lightweight state-alignment mechanism, enabling deviation tracking between the measured system and a physically consistent baseline under changing operating conditions.

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## Ⅱ. Method

Experiments were conducted on a brushed PMDC motor coupled to a 6:1 reduction gearbox and loaded using a magnetic powder brake, enabling controlled torque variation. Two piezoelectric accelerometers were installed: one on the motor housing and one on the gearbox housing, providing motor-side and reference-side vibration measurements, respectively. Torque and rotational speed were monitored during acquisition. Bearing conditions included healthy, innerrace fault, and outer-race fault. The experimental configuration is illustrated in Fig. 1.

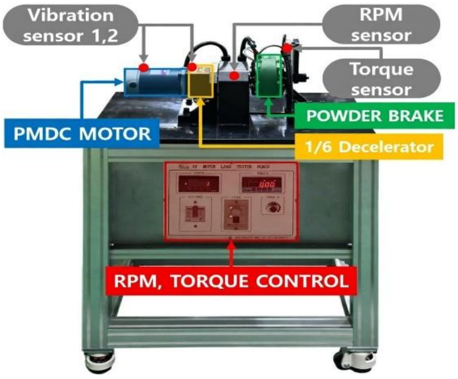


Fig1. Experimental Testbed.

Bearing defects manifest as amplitude modulation of high-frequency vibration components; therefore, both motor-side and reference signals are processed within a single diagnostic domain based on the envelope spectrum. Within each torque plateau, band-limited signals are demodulated using the Hilbert transform, and envelope spectra are computed. To suppress load-dependent amplitude scaling, each spectrum is normalized to form a distribution over frequency.

Preliminary spectral and coherence analyses indicate that motor-side and gearbox-side envelope spectra exhibit strong structural similarity across operating conditions, differing primarily in amplitude scaling. This observation motivates computation of CREA that quantify how the motor spectrum deviates from its reference counterpart. These attributes include measures of spectral similarity, bounded divergence, and band-wise energy redistribution. Importantly, no gearbox-only descriptors are provided to the classifier; the reference influences diagnosis solely through these relational features.

To prevent window-level overfitting and to support a state-based representation consistent with digital twin and real-time monitoring frameworks, envelope-domain features are aggregated robustly within torque plateaus and further summarized at the run level, yielding one feature vector per experimental run. Ongoing work evaluates lightweight classifiers using leakage-free, run-level cross-validation, with ablation studies comparing motor-only features against reference-conditioned representations. Explainability analyses are used to verify that performance gains arise from structural and relational features rather than amplitude proxies.

## Ⅲ. Conclusion

This work-in-progress investigated a reference-conditioned envelope-spectrum approach for bearing fault diagnosis in brushed PMDC motor drives operating under variable load. By exploiting the physical asymmetry between motor-mounted and gearbox-mounted vibration measurements, the gearbox signal was used solely as a baseline reference to condition interpretation of motor-side features, rather than as an independent diagnostic input.

Preliminary analyses indicate that representing vibration signals in a normalized envelope-spectrum domain and expressing motor features relative to a mechanically coupled reference can improve feature stability under stepped torque conditions when compared to motor-only baselines. Ongoing work focuses on systematic run-level evaluation, ablation studies to isolate the contribution of cross-reference envelope attributes (CREA), and explainability analysis to verify that observed trends arise from structural feature conditioning rather than amplitude effects.

From a digital twin and real-time monitoring perspective, the proposed framework provides a lightweight state-aligned sensing representation, suitable for tracking deviation from a reference-consistent system state under changing operating conditions without reliance on high-fidelity simulation models. Upon completion, this approach may serve as a practical measurement-layer component for digital twin–oriented condition monitoring of PMDC-driven systems

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## REFERENCES

[1] Nandi, S., Toliyat, H. A., & Li, X. "Condition monitoring and fault diagnosis of electrical motors—A review," IEEE Transactions on Energy Conversion, pp. 719–729, 2005.

[2] Randall, R. B., & Antoni, J. "Rolling element bearing diagnostics—A tutorial," Mechanical Systems and Signal Processing, pp. 485–520, 2011.

[3] Wang, T., Liang, M., Xiang, J., & Li, J. "Bearing fault diagnosis under variable operating conditions via adaptive multi-scale mode decomposition and time-frequency analysis," Mechanical Systems and Signal Processing, 158, 107768, 2021.

[4] Zhu, J., Yoon, J., He, D., & Bechhoefer, E. "Vibration signal processing for wind turbine bearing fault detection using cyclic coherence," IEEE Transactions on Instrumentation and Measurement, pp. 3456–3467, 2020.

[5] Li, Z., Jiang, Y., Guo, Q., Hu, C., & Peng, Z. "Multi-dimensional variational mode decomposition for bearing fault diagnosis under variable speed conditions," Measurement, 188, 110428, 2022.