A digital twin-driven cross-domain adaptation method for bearing intelligent fault diagnosis

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ABSTRACT:

Rolling bearings are key components in rotating machinery, and widely used in aerospace, high speed railways and wind turbines. Subject to frequent operation in extreme working conditions such as high loads and rotating speeds bearings are prone to unpredictable failures, which can result in equipment shutdowns and even catastrophic accidents. Therefore, reliable fault diagnosis is crucial for ensuring the safety of equipment. Traditional fault diagnosis methods rely on manually designed features and struggle to handle complex working conditions, while deep learning has improved diagnostic capability, but its demand for large amounts of labeled data limits its application under small-sample or zero-shot condition. Digital twin technology can alleviate this issue by generating simulated samples through numerical computing, but traditional cross-domain adaptation methods cannot be directly applied due to the distribution difference between simulated and measured samples. To address this issue, this paper would propose a digital twin-driven cross-domain adaptation method. The proposed method constructs a digital twins model for bearing faults based on Hertz contact theory, calibrates simulated and measured samples using cosine similarity to generate high-fidelity labeled simulated samples, and combines adversarial domain adaptation with a kurtosis weighting strategy to effectively transfer diagnostic knowledge from simulated domain to real scenarios, reducing the distribution difference. Experimental results show that the proposed method achieves an average diagnostic accuracy of 98.88% when it was trained under small-sample conditions, significantly outperforming comparative methods.