LASAR3

Laboratory of Analysis of Systems for the Assessment of Reliability, Risk and Resilience

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Cross-Modal Temporal-Spatial Synchronization for Holistic Fault Evolution Analysis in Industrial PHM Applications

Context of the research

Industrial systems face increasing reliability challenges as complexity grows and operational demands intensify. Equipment failures not only pose safety risks but also result in significant economic losses through unplanned downtime, costly repairs, and production disruptions. Prognostics and Health Management (PHM) represents an advanced approach to address these challenges by integrating detection, diagnosis, assessment, and prognosis of system failures to enable proactive maintenance strategies. PHM permits the evaluation of a system's reliability in actual life-cycle conditions, seeking to minimize maintenance costs while maximizing operational availability through early anomaly detection and failure prediction.

This thesis aims to address the fundamental challenge of integrating heterogeneous data sources in industrial PHM systems. Modern complex equipment generates vast amounts of data across different modalities (time-series sensor data, maintenance records, inspection images), yet these data exist as "information isolated islands" with inconsistent timestamps, formats, and semantic representations. The research will develop novel techniques for detecting "fault anchor points" - critical events or indicators that appear across multiple data sources - and create a unified cross-modal alignment framework that enables comprehensive fault evolution analysis.

Objective of the research

- Develop an adaptive multimodal alignment framework to synchronize heterogeneous data in temporal and event-driven dimensions, addressing sampling rate mismatches and semantic ambiguities;
- Design a fault anchor detection mechanism to identify key failure-related events across data modalities, facilitating cross-domain correlation and holistic fault pattern recognition;
- Construct a holographic dataset that integrates aligned multimodal features of system operation, enabling comprehensive modeling of fault evolution from incipient symptoms to system-level failures.

Expected Research Outcomes

The research will produce a comprehensive multimodal data processing framework capable of automatically detecting fault anchor points across time-series, text, and image modalities with high precision. The framework will include specialized feature extraction mechanisms for each data type, a cross-modal attention mechanism for information fusion, and methods to construct holistic data samples that provide complete visibility into equipment health status evolution. The work will be validated using industrial maintenance data, demonstrating significant improvements in fault detection accuracy and traceability compared to traditional single-modality approaches.

Composition of the research group

- 2 Full Professors
- 1 Associate Professor

Total thesis duration

- 8 to 12 months

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