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Soutenance de thèse de doctorat de

Hadis Hesabi

«Data-Driven Approaches for Prognostics and Health Management in Industrial Systems»

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Abstract: The fields of Prognostics and Health Management (PHM), Predictive Maintenance (PdM), and Data-Driven Approaches have emerged as transformative solutions for addressing the multifaceted challenges in maintenance practices within the complex industrial landscape. As assets continue to play a key role in an organization's productivity and competitiveness, the economic impact of maintenance becomes increasingly evident. Maintenance expenses, which can be up to 10% of production costs for individual assets, underscore the paramount importance of effective maintenance practices. Inefficiencies in maintenance not only lead to financial burdens but also entail significant consequences, such as unplanned downtime, missed production targets, safety risks, and customer dissatisfaction.

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PdM offers a promising approach to mitigate these issues. Leveraging data analytics, sensor technology, and Artificial Intelligence (AI), PdM empowers organizations to predict equipment failures with precision, allowing for planned maintenance during scheduled downtimes, thus preventing costly disruptions. However, while PdM excels in predicting potential issues, it falls short in providing comprehensive solutions for their mitigation.

In response to these challenges, PHM emerges as a multifaceted approach encompassing anomaly detection, failure diagnosis, and dynamic maintenance decision-making. The fusion of PdM and Selective Maintenance (SM) within the PHM framework represents a critical strategy in this regard. SM, particularly in complex systems with multiple interconnected components and complex maintenance scenarios, demands precise maintenance action selection, considering variables such as time, cost, and labor. The complexity is further intensified by the direct impact of these decisions on the success probabilities of future missions.

Building on this context, this thesis makes specific contributions to the fields of PHM by introducing a novel framework known as Selective Predictive Maintenance (PdSM). The framework uniquely integrates Deep Learning (DL) techniques and SM to optimize maintenance decisions for multi-component systems with consecutive missions and scheduled intermission maintenance breaks. The optimization model minimizes total costs, including maintenance and failure breakdown costs, under intermission break time limitations. A Long Short-term Memory (LSTM) classifier is employed to estimate system's failure probabilities for subsequent missions. The proposed approach is validated using NASA's benchmarking data for a Commercial Turbofan Engine, demonstrating its superior performance compared to model-based approaches.

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The second contribution builds upon the achievements of the first part, aiming to enhance the success probabilities of consecutive missions while considering intermission break time and cost limitations. This approach innovatively incorporates a Bidirectional Long Short-Term Memory (BiLSTM) classifier to estimate the success probabilities of individual components. The introduction of BiLSTM overcomes challenges associated with the unidirectional nature of traditional LSTM, allowing the model to capture dependencies in both forward and backward directions. This improvement upon LSTM results demonstrates the robustness of BiLSTM in health management for turbofan engines. Importantly, the study implements this advanced approach in a complex system, encompassing series, parallel, and network configurations. The results underscore the effectiveness of this extended methodology in advancing SM decision-making processes, contributing significantly to the improvement of maintenance strategies in systems.

The final part addresses the critical challenge of maintaining the reliability and availability of power transformers within electrical transmission and distribution systems. Conventional Dissolved Gas Analysis (DGA) techniques are augmented by data-driven approaches, utilizing various data processing steps, including label extraction, imputation, dataset balancing, and normalization. Six Machine Learning (ML) classifiers are applied, with Random Forest (RF) emerging as the top-performing model with a test accuracy of 93%. These findings emphasize the potential of ML, particularly the RF algorithm, in enhancing the accuracy of power transformer fault diagnosis. This research holds substantial implications for strengthening the stability and efficiency of electrical grids, ultimately contributing to the reliability and availability of power distribution systems.

In summary, this thesis presents innovative approaches in PHM and reliability enhancement for complex systems, providing valuable insights and methodologies that contribute to the advancement of maintenance strategies and the overall reliability of critical infrastructure.

Keywords: Predictive Maintenance, Selective Maintenance, Prognostic and Health Management, Condition Monitoring, Machine Learning, Deep Learning, Power Transformers, Dissolved Gas Analysis.

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