Universidade de Pernambuco (UPE)
Escola Politécnica de Pernambuco (POLI)
Instituto de Ciências Biológicas (ICB)

Coordenação de Pós-Graduação em Engenharia de Sistemas

Proposta de Tese de Doutorado

Área:	Cibernética
Linha de Pesquisa:	Modelagem e simulação de sistemas inteligentes e embarcados
Título Provisório:	Explainable Machine Learning for Progressive Fault Detection and Diagnosis in Industrial Machinery: An Integrated Framework for Anomaly Detection, Human-in-the-Loop Labeling, and Classification
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Co-orientador:	Emmanuel Andrade de Barros Santos (POLI-UPE)

Descrição:

The continuous digitalization of industrial environments has driven the adoption of data-driven approaches for monitoring, fault detection, and predictive maintenance. Previous research has demonstrated the potential of Automated Machine Learning (AutoML) for real-time fault detection and diagnosis (RT-FDD) in discrete manufacturing machines [1,2], and the use of anomaly detection techniques to support the labeling of scarce fault datasets [3]. However, these works have primarily focused on datasets where failures are simulated as discrete events, corresponding to sudden or specific conditions. In real-world machinery, failures rarely occur instantaneously; instead, they develop progressively, driven by physical phenomena such as fatigue, mechanical wear, shaft misalignments, looseness, or thermal insulation loss. These degradation processes gradually alter machine behavior until functional limits are reached, making their detection and diagnosis considerably more challenging [4].

This doctoral project proposes to advance the state of the art by simulating and analyzing progressive failures and anomalies, incorporating varying intensities that mimic real degradation processes in industrial equipment. The aim is to evaluate the capacity of machine learning approaches to detect and interpret these phenomena, integrating four key dimensions: (i) anomaly detection, to identify deviations from normal operation at early stages of degradation; (ii) explainable artificial intelligence (XAI), particularly SHAP and LIME, to highlight the main features and variables contributing to anomaly onset; (iii) human-in-the-loop labeling, enabling experts to use the XAI outputs to assign meaningful labels to progressive fault data; and (iv) fault classification, building supervised diagnostic models capable of distinguishing types and stages of degradation.

The methodology will involve the design of simulation environments capable of reproducing gradual deterioration in representative industrial machines, such as pick-and-place systems and furnaces. Progressive faults—such as incremental speed loss, increasing vibration amplitude due to looseness, or gradual reduction of heating efficiency—will be systematically introduced, generating datasets that reflect real degradation trajectories. Machine learning pipelines will then be tested to assess their ability to detect early deviations, attribute causality through feature relevance, and build interpretable classification models as datasets evolve. The human-in-the-loop stage will play a central role in validating the explanatory outputs, ensuring that the labeling process remains consistent with domain expertise.

The expected contributions of this research include: (i) the creation of benchmark datasets simulating progressive machine degradation; (ii) a novel framework combining anomaly detection, explainability, human-aided labeling, and classification for industrial fault diagnosis; (iii) empirical insights into the sensitivity of machine learning models to degradation intensity; and (iv) practical guidelines for implementing explainable fault detection systems in industrial settings. By addressing progressive faults—closer to real industrial conditions—this project aims to bridge the gap between academic methods and industrial practice, contributing to safer, more reliable, and cost-effective predictive maintenance strategies.

Do Candidato: Engenharia de Controle e Automação, Engenharia de Computação, Engenharia Eletrônica, Engenharia Mecânica, Engenharia de Materiais, Bacharelado em Física, Engenharia Física, e áreas afins.

Referências Bibliográficas:

[1] Leite, D.; Martins, A., Jr.; Rativa, D.; de Oliveira, J. F. L.; Maciel, A. M. A. (2022). *An Automated Machine Learning Approach for Real-Time Fault Detection and Diagnosis*. **Sensors**, 22(16), 6138. https://doi.org/10.3390/s22166138

[2] Leite, D. (2024). *An Automated Machine Learning Approach For Fault Detection and Diagnosis In Manufacturing Machines*. Doctoral Thesis, University of Pernambuco.

[3] Martins Jr., A.; Santos, E. A. B.; Leite, D.; Maciel, A. M. A. (2025). *Anomaly Detection Techniques in the Service of Data Labeling for Fault Diagnosis in Manufacturing*. In: **Proceedings of the 27th International Conference on Enterprise Information Systems (ICEIS 2025)**. https://doi.org/10.5220/0013437100003929

[4] Leite, D.; Andrade, E.; Rátiva, D.; Maciel, A. M. A. (2025). *Fault Detection and Diagnosis in Industry 4.0: A Review on Challenges and Opportunities*. **Sensors**, 25(1), 60. https://doi.org/10.3390/s25010060