Fault Detection and Predictive Maintenance of Industrial Gas Turbine Engines

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Abstract

This project aims to use sensor data to develop a machine learning-based fault detection system for industrial gas turbine engines. By leveraging a publicly available dataset from Kaggle, which includes labeled operational and faulty states, we will apply classification models, outlier detection, and time-series segmentation techniques to identify early signs of compressor failure. The system, by reducing downtime, optimizing maintenance schedules, and improving efficiency, promises to significantly enhance the operational outcomes in midstream pipeline operations where gas turbines are essential for compression.

Keywords

fault detection, gas turbines, predictive maintenance, machine learning

1 Introduction

Industrial gas turbine engines are crucial in midstream pipeline operations, powering gas compressors. Unplanned failures can lead to significant operational disruptions, economic losses, and safety hazards. This project, however, takes a proactive approach. It explores sensor-based predictive maintenance using machine learning to detect faults before they escalate into serious issues. The use of data mining for predictive diagnostics not only enhances reliability but also reduces maintenance costs and downtime.

2 Literature Review

As noted by Lei et al., the application of sensor data for predictive maintenance and fault detection has garnered considerable interest in the industrial sector. Machine learning algorithms, including Support Vector Machines (SVM), Random Forests (RF), and various deep learning models, are extensively utilized in rotating machinery diagnostics. Even rudimentary time-series data from sensors can yield favorable results.

Research by Babu et al. (2016) highlights the significance of feature engineering, especially the extraction of time-domain and frequency-domain features from temperature and vibration data for effective condition monitoring. Parameters such as pressure ratios and temperature differentials have proven useful for early failure detection.

Time-series segmentation is an evolving field of study. Malhotra et al. (2016) employed Long Short-Term Memory (LSTM) networks to identify temporal patterns, while more straightforward statistical techniques like rolling averages and trend decomposition also provide valuable insights for analyzing fault trends.

Outlier detection is a critical aspect of predictive maintenance. Techniques such as Isolation Forest (Liu et al., 2008) and DBSCAN are effective in handling noisy data and have been successfully applied in identifying equipment anomalies, particularly when the scarcity of fault labels complicates supervised learning. These techniques detect collective and contextual outliers within sensor data streams.

This project aims to synthesize insights from the aforementioned studies and apply supervised and unsupervised learning approaches to monitoring industrial gas turbine health.

3 Proposed Methodology

The dataset used for this project is the Kaggle Gas Turbine Engine Fault Detection Dataset (https://www.kaggle.com/datasets/ziya07/gas-turbine-engine-fault-detection-dataset). The dataset includes actual sensor data (e.g.,temperatures, pressures, rotational speeds, etc.) from gas turbine engines and labeled fault types. This makes it an excellent fit for supervised machine learning.

I aim to build a classification model to detect failures in gas compressors. This applies to midstream pipeline operations, where gas turbines are typically used as a compressor driving mechanism.

Dataset

- **Source:** Kaggle Gas Turbine Engine Fault Detection Dataset
- https://www.kaggle.com/datasets/ziya07/gas-turbine-engine-fault-detection-dataset

Data Preprocessing

- Missing value handling
- Sensor reading normalization
- Feature engineering (pressure ratios, temperature deltas, rolling averages, etc.)

Modeling Techniques

- **Supervised Models:** Random Forest, XGBoost, Support Vector Machines
- **Unsupervised Models:** Isolation Forest, DBSCAN
- **Time-Series Segmentation:** Apply rolling window statistics and operational cycle segmentation to detect temporal degradation patterns

Tools & Libraries

- Python (Pandas, Scikit-learn, XGBoost, Seaborn, Plotly)
- Jupyter Notebook
- Optional: Streamlit for interactive results dashboard

4 Evaluation Plan

- **Classification Metrics**

  - Accuracy
  - Precision
  - Recall
  - F1-Score
- **Anomaly Detection Metrics**
  - ROC-AUC
  - Confusion Matrix
  - Visualization of Anomalies
- **Validation Strategy**
  - K-Fold Cross-Validation to ensure robust model performance across different subsets of the data
- **Interpretability**
  - Use SHAP values or feature importances to explain and interpret model predictions

5 Timeline

This timeline outlines the key phases of the project, beginning with literature review and data preparation, followed by model development and anomaly detection. The final days are allocated to compiling results and preparing the final report and presentation. Table 1 summarizes the major project milestones. The project is scheduled for completion by April 28, 2025, aligning with the course submission deadline.

6 Citations and Bibliographies

This project builds on a range of research studies and industry data sources. The core background for this work includes a comprehensive survey on anomaly detection by Chandola et al. [2] and a foundational review of machinery health prognostics by Lei et al. [5]. Isolation Forest, introduced by Liu et al. [6], is among the primary algorithms employed in our anomaly detection phase. Time-series segmentation is informed by Malhotra et al.'s work on TimeNet [7], while the importance of predictive maintenance is reinforced by recent market insights from IoT Analytics [4]. Additionally, an Applied Sciences journal article [1] presents a helpful overview of current machine learning models in gas turbine anomaly detection. The dataset used for experimentation is the Gas Turbine Engine Fault Detection Dataset hosted on Kaggle [3].

References

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Table 1: Proposed Project Timeline

Phase	Dates	Tasks
Project Planning & Literature Review	Apr 16 – Apr 18	Finalize proposal, conduct literature review, outline methods
Data Preparation & EDA	Apr 18 – Apr 20	Clean dataset, perform exploratory data analysis, and engineer features
Model Building (Classification)	Apr 20 – Apr 23	Train and evaluate Random Forest, XGBoost, and SVM models
Outlier Detection & Time-Series Analysis	Apr 23 – Apr 25	Apply Isolation Forest, DBSCAN, and segment time-series data for degradation pattern analysis
Final Report & Presentation	Apr 25 – Apr 28	Compile results, write final report, and prepare presentation materials