PREDICTIVE EQUIPMENT MAINTENANCE FOR HYDRAULIC SYSTEMS USING MACHINE LEARNING

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Abstract

- **Reason for Writing:** Hydraulic systems are critical in many industries but vulnerable to faults that can affect performance and safety, necessitating predictive maintenance.
- **Problem:** There is a need for a predictive model that monitors and anticipates hydraulic component failures while exploring correlations between condition variables.
- **Methodology:** This research developed a predictive maintenance model using machine learning and deep learning techniques, including feature scaling, extraction, and selection, and evaluated three classifiers: random forest, catboost, and LSTM.
- **Results:** The results demonstrate that the Catboost model performed the best overall, achieving perfect scores across multiple components.

Problem Statement

Hydraulic systems in industries like petroleum and aerospace are prone to faults, risking severe damage and accidents. Current methods for fault prediction are inadequate due to ineffective feature extraction, poor data correlation, suboptimal classifier training, and unreliable predictions. This project aims to develop a predictive model to forecast maintenance needs, analyze sensor data, and understand condition variable correlations over time. The goal is to reduce failure risks, enhance equipment performance and efficiency, and save costs and resources.

Objectives

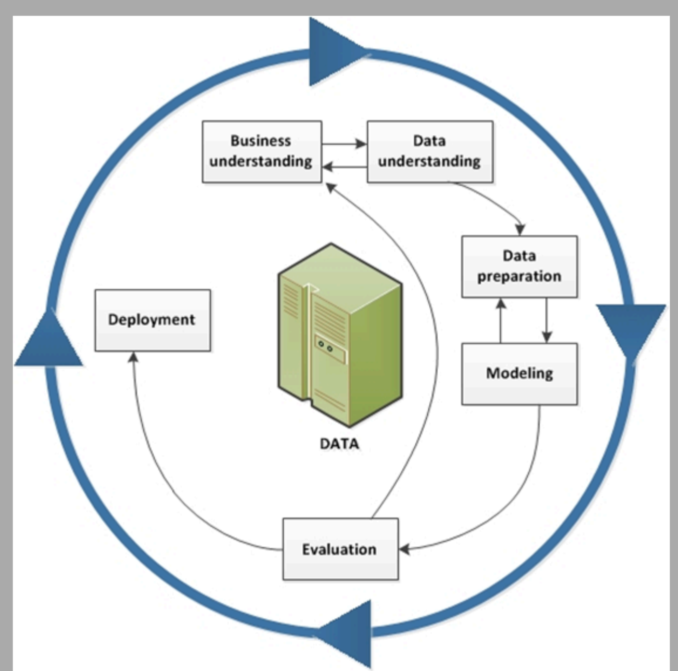
- To perform a literature survey on techniques for correlating condition variables in Predictive Equipment Maintenance in the Hydraulics System.
- To design and implement machine learning models using condition variables in Predictive Equipment Maintenance.
- To evaluate the performance of the models using different metrics and identify the optimal model.

Background Research

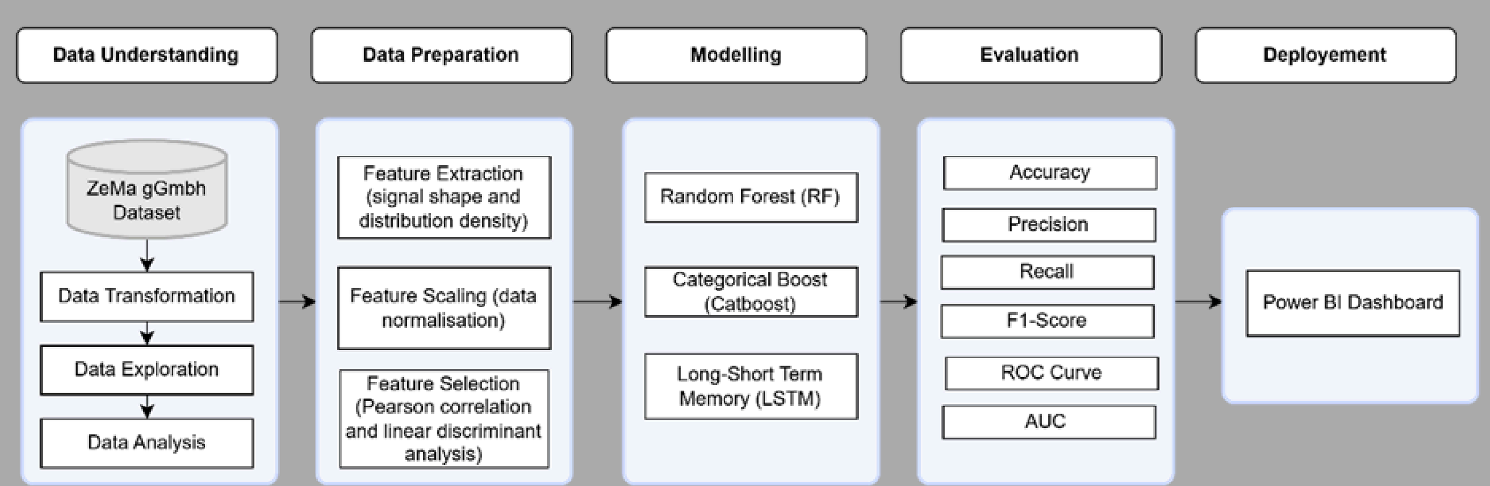
- Hydraulic systems, crucial in industries like petroleum and aerospace, efficiently transmit power using liquid under high pressure. Condition monitoring uses sensor data to detect equipment degradation, enabling timely maintenance to prevent failures (Beebe, 2004). Predictive maintenance employs techniques such as vibration and oil analysis to estimate equipment life and plan preventive actions (Levitt, 2003).
- Previous research has utilized various machine learning and deep learning algorithms to predict faults in hydraulic systems, focusing on different system conditions and failure stages (Helwig et al., 2015; Schneider et al., 2018).
- However, the correlation between condition variables is underexplored, and deep learning techniques are often overlooked. This project aims to address these gaps by enhancing predictive maintenance models through comprehensive data analysis and advanced algorithms, improving system reliability and efficiency.

Theoretical Framework

This research uses the CRISP-DM framework for predictive maintenance of hydraulic systems. It employs Random Forest, CatBoost, and LSTM models, evaluated by Precision, Recall, F1-Score, Accuracy, ROC Curve, and AUC. Results are visualized with Power BI for decision-making.



Research Methodology



Implementation

The implementation started with extracting and cleaning hydraulic system data, resulting in a data frame of 2205 rows and 22 columns. Data preparation included feature extraction, normalization, and feature selection via Pearson Correlation and LDA. Random Forest, Catboost, and LSTM models were trained with all features, Pearson-selected features, and LDA-selected features. Performance was evaluated using accuracy, precision, recall, F1-score, and ROC AUC.

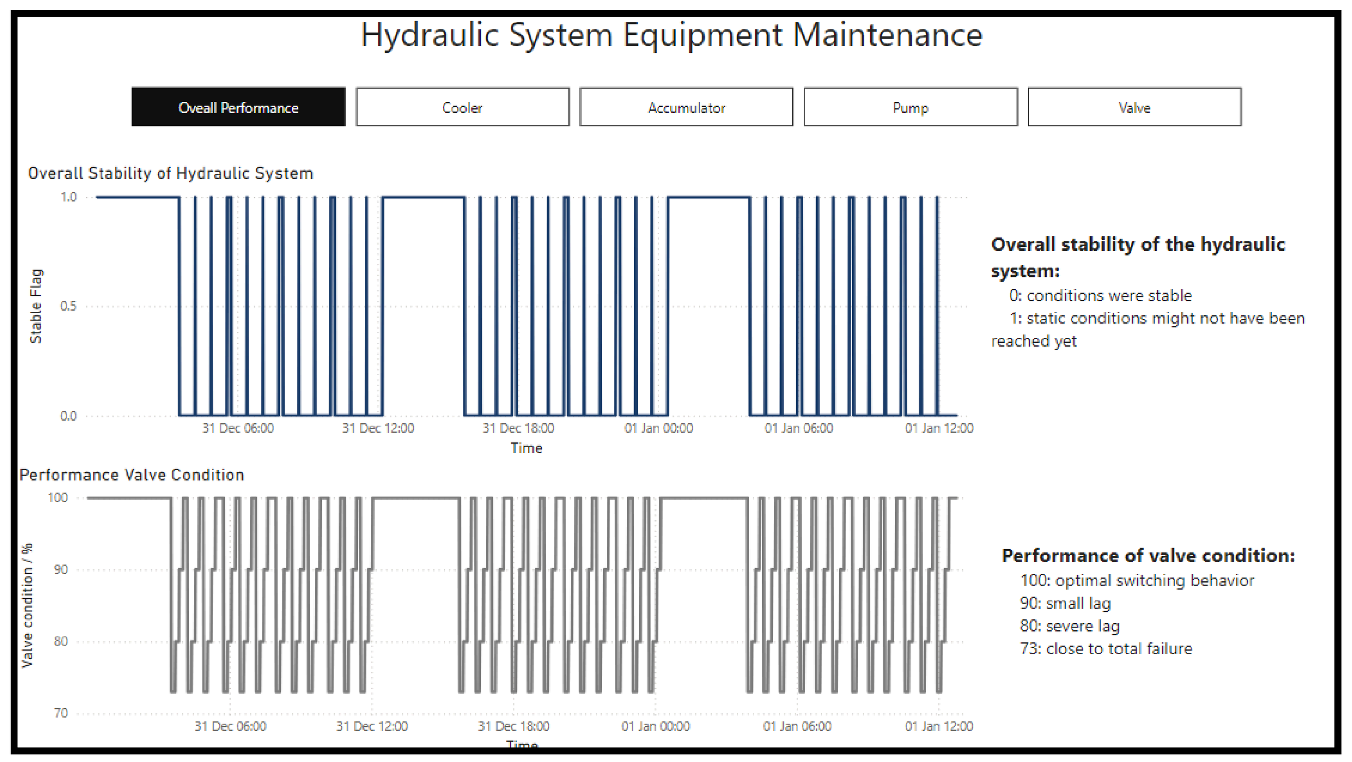
Results and Discussion

The testing phase evaluated models across three phases with hyperparameter tuning. Random Forest and Catboost excelled, especially for the Cooler component with perfect scores. LSTM models were less consistent, with performance declining for Valve and Accumulator components at larger batch sizes. Phase 1 with no feature seleection had the best accuracies, particularly with Catboost and Random Forest.

Phase 1 - No Feature Selection		
Model	**Conditioning Component**	**Accuracy**
Random Forest	Cooler	100.000%
	Valve	99.335%
	Internal Pump Leakage	99.320%
	Accumulator	99.093%
	Stable Flag	98.413%
Catboost	Cooler	100.000%
	Valve	100.000%
	Internal Pump Leakage	98.866%
	Accumulator	97.732%
	Stable Flag	99.093%
LSTM	Cooler	100.000%
	Valve	89.569%
	Internal Pump Leakage	97.959%
	Accumulator	90.930%
	Stable Flag	95.692%

Dashboard

Using the dataset provided by ZeMA gGmbH, a dashboard was created to display charts of the condition components of the hydraulic system. The time column was manually calculated, revealing that the test rig ran for a total of 36 hours and 45 minutes. The dashboard includes several key pages: the "Overall Performance" page shows the correlation between system stability and valve condition over time. The "Cooler Performance" page highlights improvements in cooler efficiency and its relation to sensor readings. The "Accumulator Performance" page reveals cyclic pressure drops, indicating reduced efficiency periods. The "Internal Pump Performance" page monitors recurring leakage issues. Lastly, the "Valve Performance" page tracks valve condition fluctuations, aiding in identifying critical maintenance times.



Conclusion

This project explored predictive maintenance for hydraulic systems using machine and deep learning. It covered data collection, preparation, modelling, evaluation, and deployment. Catboost and Random Forest models performed best, especially for the Cooler component, while LSTM models were inconsistent. Feature selection slightly improved performance. Lastly, a dashboard is demonstrated using Power BI.

Reference & Publication

Beebe, R. S. (2004). Predictive maintenance of pumps using condition monitoring. Elsevier.
Levitt, J. (2003). Complete guide to preventive and predictive maintenance. Industrial Press Inc.
Helwig, N., Pignanelli, E., & Schutze, A. (2015, May). Condition monitoring of a complex hydraulic system using multivariate statistics. 2015 IEEE International Instrumentation and Measurement Technology Conference (I2MTC) Proceedings. http://dx.doi.org/10.1109/i2mtc.2015.7151267
Schneider, T., Klein, S., & Bastuck, M. (2018, April 26). Condition monitoring of hydraulic systems Data Set at ZeMA. Zenodo. https://zenodo.org/records/1323611

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- Working on the second paper, which includes implementing feature selection to improve accuracy.