

Predictive Maintenance (PdM) of BLDC Motor and Anomalies Using Machine Learning

Abstract

This research addresses the critical need for reliable predictive maintenance (PdM) in Brushless DC (BLDC) motors, which are integral to robotics and unmanned aerial vehicles (UAVs). Traditional maintenance often fails to detect early-stage mechanical faults, leading to unexpected failures. This proposal outlines a machine learning-based framework to identify motor anomalies and predict the remaining useful life (RUL) using acoustic and vibration data. By integrating advanced feature extraction techniques like Wavelet Transform with ensemble learning models, the study aims to achieve high diagnostic accuracy while addressing current limitations in model generalization and ambient noise interference.

Chapter 1: Introduction

1.1 Background

Brushless DC (BLDC) motors have become the standard for high-performance applications such as aerial robotics and industrial machinery due to their efficiency and reliability. However, these motors are susceptible to various mechanical and electrical faults, including bearing failures, chipped propellers, and eccentric shafts. Predictive Maintenance (PdM) leverages data-driven techniques to monitor equipment health and schedule maintenance before failures occur. Recent advancements in Machine Learning (ML) and Deep Learning (DL) have shown promise in classifying motor conditions with high accuracy using sensor data such as sound and vibration.

1.2 Problem Statement

Despite the potential of ML in predictive maintenance, significant challenges hinder its practical deployment. Current research is highly fragmented, lacking standardization in data types, algorithms, and architectures. Specific technical hurdles include:

- **Acoustic Similarity:** ML models often struggle to distinguish between normal operational sounds and anomalous signals because they are acoustically similar.
- **Environmental Noise:** Real-time inferencing is frequently compromised by ambient noise, leading to reduced accuracy in non-controlled environments.
- **Generalization:** Models trained on specific experimental setups often fail to generalize to different motor types or operational conditions.
- **Hardware Constraints:** Many existing solutions require high-performance computers for analysis, limiting the feasibility of real-time edge computing on low-cost microcontrollers.

1.3 Research Objectives

1. To develop a robust feature extraction method using Wavelet Transform and Fast Fourier Transform (FFT) to isolate fault signals from ambient noise.
2. To design and compare the performance of multiple ML algorithms (e.g., Bagged Trees, Isolation Forest, and CNNs) in identifying diverse BLDC motor anomalies.
3. To propose a multi-layered architecture (Edge, Cloud, and Sensor layers) that enables both real-time anomaly detection and long-term RUL prediction.
4. To validate the framework's effectiveness across different operational environments to improve model generalization.

1.4 Research Scope

The scope of this research focuses specifically on BLDC motors commonly used in UAVs and robotics (such as the A2212 model). The data acquisition will be limited to acoustic (sound) and vibration signals. The study will evaluate maintenance conditions including "healthy," "faulty bearing," "chipped propeller," and "eccentric shaft". It will not cover other motor types or environmental factors beyond standard operating noise.

Chapter 2: Literature Review

The field of Predictive Maintenance for BLDC motors is evolving through various sensor-based ML approaches.

- **Acoustic Analysis:** Tekin and Kaya (2024) demonstrated that mechanical faults can be detected early through sound using Wavelet Transform features and Bagged Trees, achieving 89% accuracy. However, they noted that ambient noise remains a primary barrier to real-time application.
- **Standardized Datasets:** Prieto Estacio et al. (2023) provided critical datasets for UAV motors but emphasized that data collected in controlled environments may not be directly applicable to real-world scenarios.
- **Vibration and IoT:** Kolok et al. (2025) utilized Isolation Forest algorithms and vibration data for low-cost IoT maintenance, though they were limited by the processing power of the microcontrollers used.
- **Deep Learning Frameworks:** Hafiz et al. (2025) achieved a high accuracy of 97% using CNNs for industrial sound classification but highlighted the difficulty in distinguishing between acoustically similar operational states.
- **Comprehensive Architectures:** Andrioaia and Gaitan (2025) proposed three-layer architectures to combine motor fault identification with battery RUL prediction, though their models faced challenges with generalization across different setups.

Chapter 3: Research Methodology

3.1 Research Design

This study will follow a quantitative experimental design involving four main phases:

1. **Data Acquisition:** Collecting sound and vibration data from BLDC motors using IoT-connected microphones and accelerometers under both controlled and noisy conditions
2. **Preprocessing:** Applying Wavelet Transform and FFT to extract relevant features and filtering techniques to mitigate ambient noise.
3. **Model Training:** Training and evaluating ensemble ML models and CNNs to classify motor states.
4. **System Implementation:** Designing a layered architecture where the edge layer handles initial processing and the cloud layer performs complex RUL analysis.

3.2 Expected Outcomes

- A refined ML framework capable of at least 90% accuracy in fault classification across different environments.
- A validated filtering method to improve the reliability of acoustic diagnostics in noisy industrial settings.
- A set of guidelines for deploying PdM systems on low-cost hardware.

3.3 Gantt Chart

Task	Month 1	Month 2	Month 3	Month 4	Month 5
Literature Review	X				
Data Collection		X			
Feature Extraction & Filtering		X	X		
Model Training & Testing			X	X	
Results Analysis & Final Report					X

References

1. B. Tekin and T. Kaya, "Analysis of Brushless DC Motor Sounds with Machine Learning Methods Using Wavelet Transform Based Features," 2024.
2. R. S. P. Estacio et al., "Dataset of audio signals from brushless DC motors for predictive maintenance," 2023.
3. P. Kolok et al., "Low-Cost IoT-Based Predictive Maintenance Using Vibration," 2025.
4. D. A. Andrioaia and V. G. Gaitan, "Predictive Maintenance System to RUL Prediction of Li-Ion Batteries and Identify the Fault Type of BLDC Motor," 2025.
5. N. F. M. Hafiz et al., "Machine Learning Framework for Industrial Machine Sound Classification in Predictive Maintenance," *IEEE Access*, 2025.