

Deep Learning for Bearing Fault Detection in Electric Aircraft Using Current and Vibration Signals

Oliwia Frankiewicz¹, Jeremi Jarosz¹, Maciej Skowron¹, Jerome Valire², Sebastien Weisse², Krzysztof Szabat¹
¹ Wrocław University of Science and Technology, Poland | ² SAFRAN Electrical & Power, France

The increasing electrification of transport, including cars and aircraft, creates a growing need for highly reliable electric motors. Among their components, rolling bearings remain the most frequently failing parts, and early fault detection is critical to ensuring safety, reducing downtime, and lowering maintenance costs. In this study, we explore a novel diagnostic approach based on convolutional neural networks (CNNs) for the direct analysis of diagnostic signals such as vibrations and phase currents. The proposed CNN-based solution enables fast and highly accurate detection and classification of bearing defects using a minimal number of samples, making it particularly suitable for electromobility and aviation applications, where short response times and high operational reliability are essential.

This research is significant in the context of aviation electrification and environmental impact reduction. Achieving climate-neutral air mobility by 2050 requires a drastic shift towards electric and hybrid-electric propulsion for larger aircraft, necessitating high-power electrical distribution systems. Ensuring the safety of these critical systems is paramount. Bearing damage is a frequent cause of failure in electric machines [1], and early detection is crucial to prevent further damage and ensure safety. This work contributes to the development of reliable diagnostic tools for these critical components in electrified aircraft. The general structure of such a damage detection system is illustrated in Figure 1.

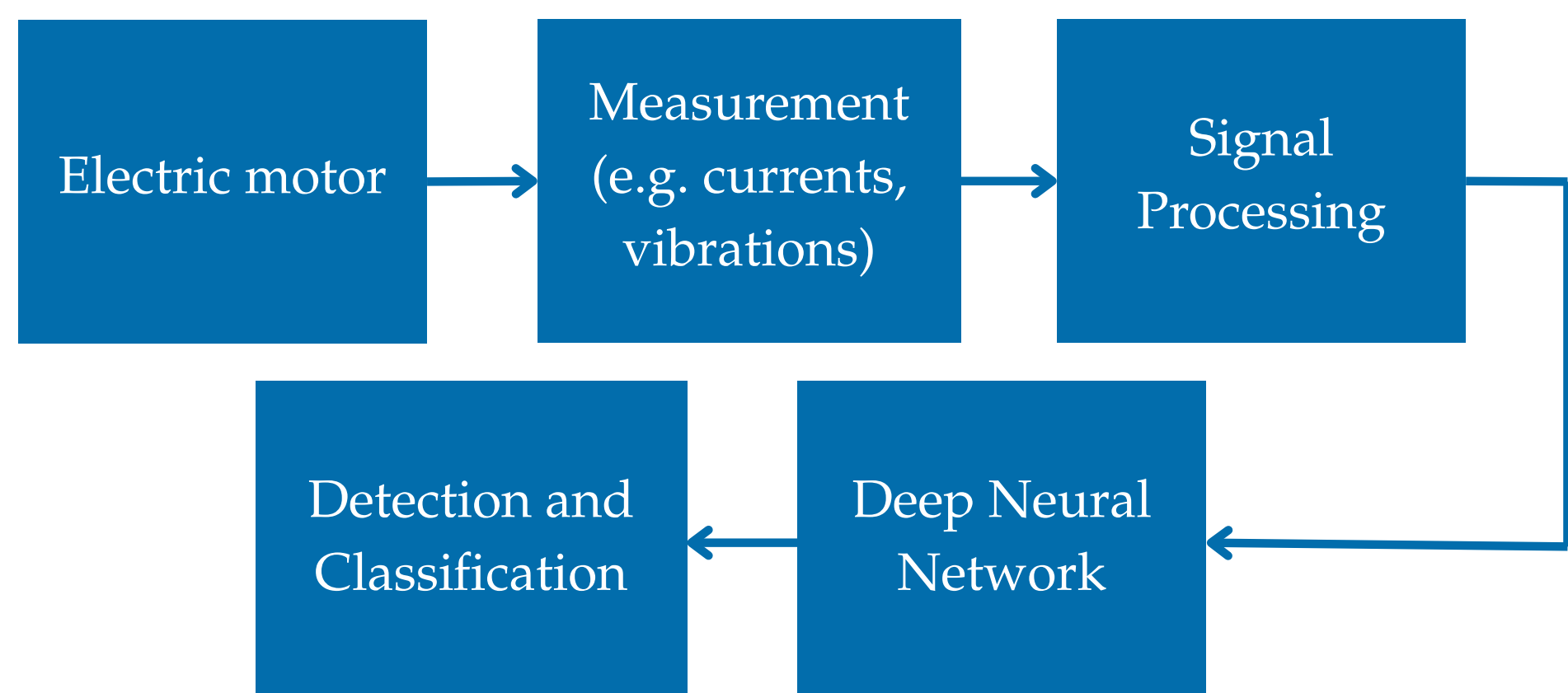


Figure 1. General Block Diagram of the Damage Detection System

Rolling bearing fault detection systems for aviation applications

Diagnostic systems for electromobility, especially in aviation, must meet a range of stringent requirements:

- **Rapid detection:** To ensure safety, fault detection must occur within a very short timeframe, minimizing the risk of critical component failures.
- **Hardware implementation feasibility:** The neural network architecture and measurement systems must be optimized for real-time processing on microprocessors with limited computational power and memory.

Experimental Setup

The experiments were conducted on a 1.5kW Sh90L-4 induction motor mechanically coupled with a PZBb44b DC motor acting as a controllable load. The motor was equipped with SKF6205-Z bearings, where various types and levels of damage were introduced to the outer race, inner race, rolling elements, and cage. In total, 12 damage classes were investigated, covering different components and severities of defects. The tests were carried out under variable load conditions ranging from 0% to 100% of the nominal torque in 20% increments.

- **High detection reliability:** False alarms can lead to significant operational disruptions, including delayed or canceled flights, resulting in substantial financial losses for airlines.

Our CNN-based approach, which uses direct phase current analysis, demonstrated high classification efficiency (99.85%–99.94% accuracy) [3]. This method achieved high precision with a short data acquisition time (50 ms), offering a reliable and efficient diagnostic tool for electrical machinery, well-suited for the demands of electrified aircraft. Given the hardware constraints typical of embedded drive control systems, a key focus of this work was the optimization of both the neural network architecture and the input vector size. This optimization enabled effective fault detection with input data ranging from only 100 to 600 signal samples. For example, the Net-100 model processes as little as 2.34 kB of input data with a mean response time of 0.039 ms, while the larger Net-600 model achieves higher accuracy at the expense of a slightly longer processing time. This balance ensures reliable diagnostics within strict computational and memory limits.

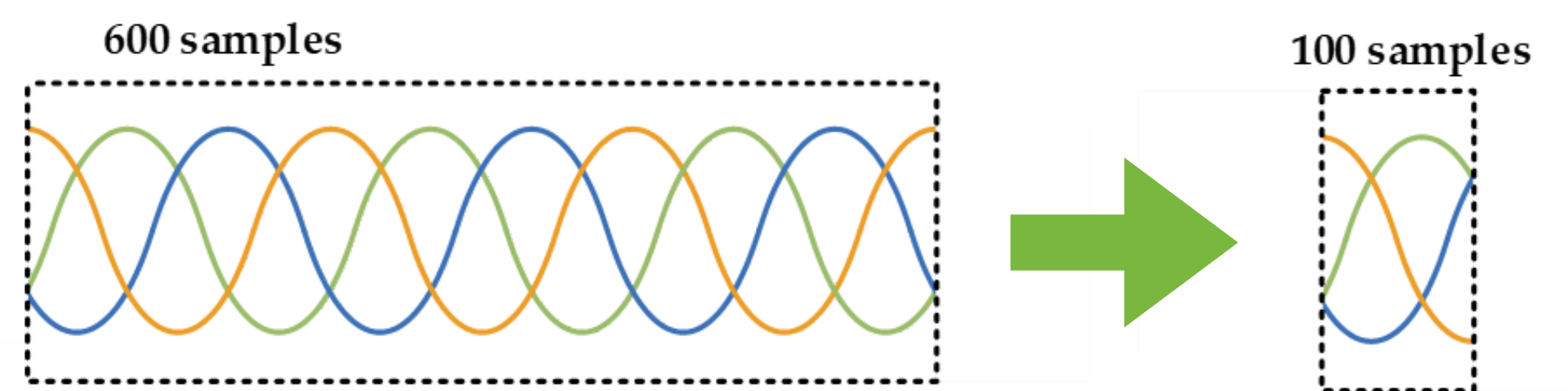


Figure 2. Comparison of input vector lengths (600 samples - 3 periods, 100 samples - half a period)

Additionally, these networks were tested for robustness against noise by adding artificial disturbances to the input signals. Networks utilizing input vectors of size 400 to 600 demonstrated the highest resilience to noise interference.

Comparison of vibration and current signals

Traditional vibration analysis is a widely used method for bearing fault detection and can achieve very high accuracy (up to 99.8% in our CNN-based research [2]) under controlled laboratory conditions. However, vibration signals are highly sensitive to external interference and require stable operating conditions, which limits their practicality in real-world applications. This is particularly challenging in dynamic environments such as electromobility, where operating conditions change rapidly and cannot be easily stabilized. In contrast, phase currents are often already measured in closed-loop control systems of electric drives, which makes them an attractive alternative diagnostic signal that does not require additional sensors, unlike vibration-based methods. Nevertheless, detecting and classifying bearing faults from phase current signals is a more complex task due to the indirect and less pronounced manifestation of mechanical defects in electrical signals.

In summary, the proposed CNN-based diagnostic system demonstrates high classification accuracy and robustness to noise, making it a promising solution for electrified aircraft applications. Diagnostic systems used in electromobility must meet a range of strict requirements, including high reliability, fast response times, and the ability to operate within limited hardware resources.

Compared to other diagnostic signals, phase current measurements are particularly advantageous due to their direct availability from existing sensors, non-invasiveness, and relatively low cost, making them an excellent choice for real-time fault detection.

Read more about
the project:

