Intelligent Diagnostics of Electrical Machines through AI-Enabled IoT Systems: Design of Custom Embedded Hardware and Protocol-Aware Architectures for Industrial Applications

Summary

The main objective of this research project is to develop an integrated diagnostic system for electrical machines based on custom-designed embedded hardware and edge-deployable AI models. Building upon prior work that established basic IoT connectivity and AI-based fault detection methods, this research will advance toward a deployable industrial solution by developing a custom PCB platform for real-time condition monitoring, on-device inference, and industrial communication. The system will incorporate optimized machine learning algorithms, support standardized IoT protocols, and be validated in laboratory and semi-industrial environments. The project contributes to smart maintenance strategies within the broader context of Industry 4.0 and is part of an ongoing initiative to enable predictive diagnostics for electrical machines.

Research field:	Electrical power engineering and mechatronics
Supervisors:	Dr. Toomas Vaimann Hadi Ashraf Raja
Availability:	This position is available.
Offered by:	School of Engineering Department of Electrical Power Engineering and Mechatronics
Application deadline:	Applications are accepted between June 01, 2025 00:00 and June 30, 2025 23:59 (Europe/Zurich)

Description

The research

The increasing need for predictive maintenance in industrial applications has accelerated the development of AI- and IoT-enabled condition monitoring systems. Previous research in this domain has successfully demonstrated the feasibility of IoT-based data acquisition and AI-based fault detection for electrical machines. This PhD project will build upon that foundational work by focusing on the **design, implementation, and validation of a custom embedded diagnostic platform**—bridging the gap between proof-of-concept and industrial deployment.

The hardware component of the research will involve the **development of a custom PCB**, integrating sensing modules (e.g., vibration, current, voltage), analog and digital signal processing circuits, microcontrollers or SoCs, and power management systems. The board will be optimized for **industrial environments**, addressing constraints such as electromagnetic interference (EMI), thermal stability, and mechanical durability.

In parallel, the project will refine and optimize existing machine learning models for fault detection and prediction, focusing on **efficient edge deployment** (e.g., through model pruning, quantization, or TinyML techniques). The embedded system will be designed to perform local inference in real-time, minimizing latency and network dependency.

On the communication side, the system will utilize standardized industrial **IoT protocols** such as **MQTT**, **OPC-UA**, and **Modbus TCP** to enable efficient, secure, and low-latency transmission of diagnostic data to **cloud-based platforms** for further analysis, visualization, and integration with digital maintenance workflows. Particular attention will be given to **data security**, **integrity**, and **communication reliability** under industrial operating conditions.

Key research questions:

1. How can a custom embedded platform be designed for reliable, real-time diagnostics in industrial settings?
2. Which sensing modalities and signal processing techniques are optimal for machine condition monitoring?
3. How can existing AI models be adapted for resource-constrained edge inference?
4. What are the trade-offs between communication bandwidth, inference latency, and diagnostic accuracy?
5. How can the developed system be validated and benchmarked in representative environments?

Responsibilities and (foreseen) tasks

- Review of embedded system design principles for industrial condition monitoring
- Design, simulation, and fabrication of a custom PCB for edge AI diagnostics
- Optimization of ML models for real-time inference (using Python, C++, TinyML)
- Integration of sensing, signal processing, and communication subsystems
- Implementation and testing of industrial IoT communication protocols
- Experimental validation in laboratory testbeds or pilot industrial deployments
- Contribution to academic publications and collaboration with partner organizations

Applicants should fulfil the following requirements:

- Master's degree in electrical engineering, embedded systems, or a related field
- Clear interest in industrial diagnostics, AI, and hardware/software co-design
- Good command of English (spoken and written)
- Strong analytical and documentation skills
- Experience with PCB design (e.g., Altium Designer, KiCad, Eagle)
- Programming experience in Python and embedded C/C++

(The following experience is beneficial:)

- Familiarity with AI/ML frameworks (e.g., TensorFlow Lite, Edge Impulse)
- Experience working with microcontrollers or SoCs (e.g., STM32, ESP32, ARM Cortex-M)
- Understanding of industrial communication protocols and automation systems
- Prior work with condition monitoring or predictive maintenance
- Experience publishing or presenting technical or scientific work

The candidate should submit a research plan for the topic, including the overall research and data collection strategy. The candidate can expand on the listed research questions and tasks, and propose theoretical lenses to be used.

We offer:

- 4-year PhD position in one of the largest, most internationalized and leading social science research centers in Estonia with a large portfolio of ongoing pan-European and national public administration, digital governance and innovation studies projects
- The chance to do high-level research in one of the most dynamic digital government contexts globally
- Opportunities for conference visits, research stays and networking with globally leading universities and research centers in the fields of public administration, innovation studies and digital government

About the department

The Department of Electrical Power Engineering and Mechatronics of Tallinn University of Technology is an interdisciplinary research center that focuses on socially relevant and future-oriented research and teaching issues related to power engineering and mechatronics. The mission of the Department is to be a leader in electrical engineering and technical studies and development projects in Estonia, known and valued in society, and a respected partner in both national and international cooperation networks and organizations.

The department educates future electrical and power engineering leaders and engineers at the bachelor's, master's and doctoral level. Through training courses, the department ensures lifelong learning and continuous development.

The department carries out large-scale interdisciplinary scientific research, development and professional projects, thanks to which the competence in the field of electrical energy and mechatronics continues to grow. With research, application and development services, the department increases the competitiveness of companies in both the domestic and international markets, keeping knowledge in Estonia. The department has coordinated or been a partner in numerous international projects, such as Horizon 2020, INTERREG, 7FP, Nordic Energy Research, etc.

The Department of Electrical Power Engineering and Mechatronics conducts research within seven research groups and operates state of the art laboratories with high end equipment, offering also accredited services in the fields of lighting and different electrical measurements.

The departments' focus areas are related to both domestic and global developments, such as increasing digitalization and decarbonization, decentralization and decentralization of electricity generation, and the increasing use of renewable energy sources. The department conducts research in the following relevant areas tackling the energy transition:

- optimization of electrical systems and system analysis to find possibilities for electrification and decarbonization
- diagnostics and monitoring of equipment and systems
- cyber security, 5G data communications and artificial intelligence
- energy networks and research on hydrogen technologies, including energy storage, renewable energy, low carbon technologies, consumption management, IoT applications in energy
- implementation of smart industry, including industrial robotics, automation, 3D printing, machine vision
- implementation of energy and resource efficiency, including digitization of supply chains, mapping of opportunities to optimize systems and reduce energy consumption
- development of smart city solutions, including environmentally friendly and self-driving vehicles / drones, digital twin applications.

(Additional information)

For further information, please contact Prof Toomas Vaimann toomas.vaimann@taltech.ee and Dr. Hadi Ashraf Raja hadi.raja@taltech.ee

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