AI-Driven Battery Life Optimization for V2X-Enabled Software-Defined Vehicles

Summary

The overall goal of the project is to develop AI-driven battery management strategies for V2X-enabled Software-Defined Vehicles (SDVs) to enhance energy efficiency, extend battery lifespan, and optimize power distribution. The project addresses the following research questions: How can artificial intelligence and real-time data analytics be used to predict battery degradation and optimize charging cycles in SDVs? What are the most effective methods for integrating multi-domain battery models into SDV architectures for improved performance and control? How can hybrid AI- and physics-based optimization strategies be designed to support predictive maintenance and adaptive energy management under dynamic driving conditions?

Research field:	Electrical power engineering and mechatronics
Supervisors:	Alar Kuusik 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

This PhD project aims to develop intelligent battery management strategies for V2X-Enabled Software-Defined Vehicles (SDVs) by leveraging artificial intelligence (AI), IoT-based sensors, and real-time data analytics. The goal is to enhance energy efficiency, extend battery lifespan, and optimize power distribution within SDVs by integrating predictive modeling, machine learning, and advanced control strategies.

The research will focus on developing AI-powered algorithms to assess battery health, predict degradation patterns, and optimize charging/discharging cycles based on real-time environmental and operational data. Additionally, the project will incorporate IoT-enabled monitoring to enable adaptive power control and predictive maintenance. The study aims to improve battery performance under dynamic driving conditions while ensuring computational efficiency in software-defined vehicle architectures.

The thesis should address all or some of the following questions: 1) How can artificial intelligence and real-time data analytics be used to predict battery degradation and optimize charging and discharging cycles in Software-Defined Vehicles (SDVs)? 2) What are the most effective methods for integrating multi-domain battery models—encompassing electrical, thermal, electrochemical, and mechanical aspects—into SDV architectures? 3) How can hybrid AI- and physics-based optimization strategies be developed to support predictive maintenance and extend battery life under dynamic operational and environmental conditions? 4) What technical and computational capabilities are required to enable scalable, adaptive energy management in IoT-enabled, V2X-connected vehicle systems?

Responsibilities and (foreseen) tasks

- Understanding of AI-driven energy management in SDVs
- Conduct an extensive literature review on AI-driven energy management, digital twins, and IoT-based battery monitoring in SDVs.
- Analyze the current methodologies and identify gaps to refine research objectives.
- Research into state-of-the-art technologies and methodologies
  - Identify and review existing AI-driven battery management techniques, IoT-based monitoring systems, and SDV architectures.
  - Explore recent advancements in neural networks, reinforcement learning, and predictive modeling techniques for power management.
  - Review existing analytical, numerical, and data-driven models related to battery management in SDVs.
- Multi-domain battery modeling and integration

- Develop multi-domain battery models that capture electrical, electrochemical, thermal, and mechanical interactions.
- Ensure accurate integration of battery models into SDV digital twin frameworks.
- Address cross-domain dependencies and evaluate their effects on battery performance.

- Development of hybrid AI-driven optimization strategies
  - Design and implement hybrid optimization models that combine deep learning and physics-based approaches for battery life extension.
  - Develop AI-based predictive maintenance techniques for early fault detection and anomaly detection in battery systems.
  - Implement multiscale modeling methods to bridge component-level (micro) and system-level (macro) energy management strategies.
- Empirical validation of the proposed models
  - Validate developed battery management models using experimental data from IoT-enabled sensor networks and real-time simulations.
  - Conduct sensitivity analysis under varying operational conditions, including environmental factors such as temperature and load variations.
  - Benchmark model performance against existing battery management solutions to assess improvements in efficiency and longevity.

Applicants should fulfil the following requirements:

- Master's degree in electrical engineering, mechatronics, or a related field.a clear interest in the topic of the position
- Strong programming skills in Python, with experience in machine learning frameworks (TensorFlow, PyTorch, Scikit-learn)
- Familiarity with multi-domain simulation tools (e.g., Matlab, Simulink, Octave) and modeling techniques
- Experience with AI, neural networks, and predictive modeling techniques applied to power systems
- excellent command of English
- strong and demonstrable writing and analytical skills
- capacity to work both as an independent researcher and as part of an international team
- capacity and willingness to provide assistance in organizational tasks relevant to the project

(The following experience is beneficial:)

- Practical experience with battery management systems, lithium-ion battery modeling, and state-of-health estimation
- Experience with IoT protocols (MQTT, LoRa, BLE) and sensor integration for real-time battery monitoring
- Practical experience in publishing and presenting research work (e.g., conference papers, journal articles)
- Fluent Estonian language skills in written and oral communication are desirable but not mandatory

This PhD opportunity provides a unique chance to work at the forefront of AI-driven battery optimization in software-defined electric vehicles, contributing to the future of energy-efficient and intelligent mobility solutions. The candidate will collaborate with experts in machine learning, power systems, and IoT and gain hands-on experience through simulations, hardware-in-the-loop (HIL) testing, and prototype development.

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

(Additional information)

Main supervisor: Hadi Ashraf Raja

Co-supervisor: Alar Kuusik

For further information, please contact Prof Anton Rassõlkin anton.rassolkin@taltech.ee.

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