Applying Machine Learning Technologies to Predictions for Lithium-ion Batteries

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Abstract

- Battery cells/pack are widely used in Electric Vehicles and Hybrid Electric Vehicles (HEVs), portable power tools and x-ray machines [1].
- Predicting or estimating battery attributes such as remaining useful life (RUL) and cell temperatures are vital concepts in a battery management system.
- RUL is the number of battery cycles from its rated capacity to the end of its life (EOL).

$$RUL = N_{eol} - N$$

- On the other hand, without accurate cell temperature prediction and effective thermal management, batteries can become overheat, cause lethal problems. The overall cycle life of the battery will be shortened.

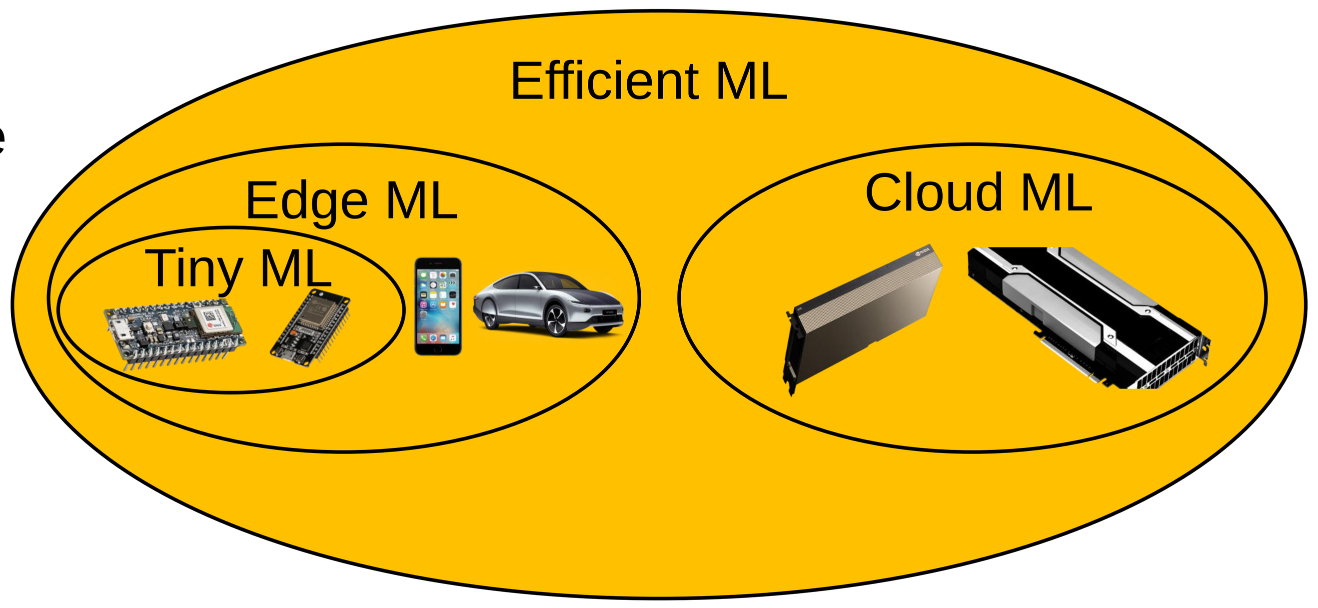
Related Work

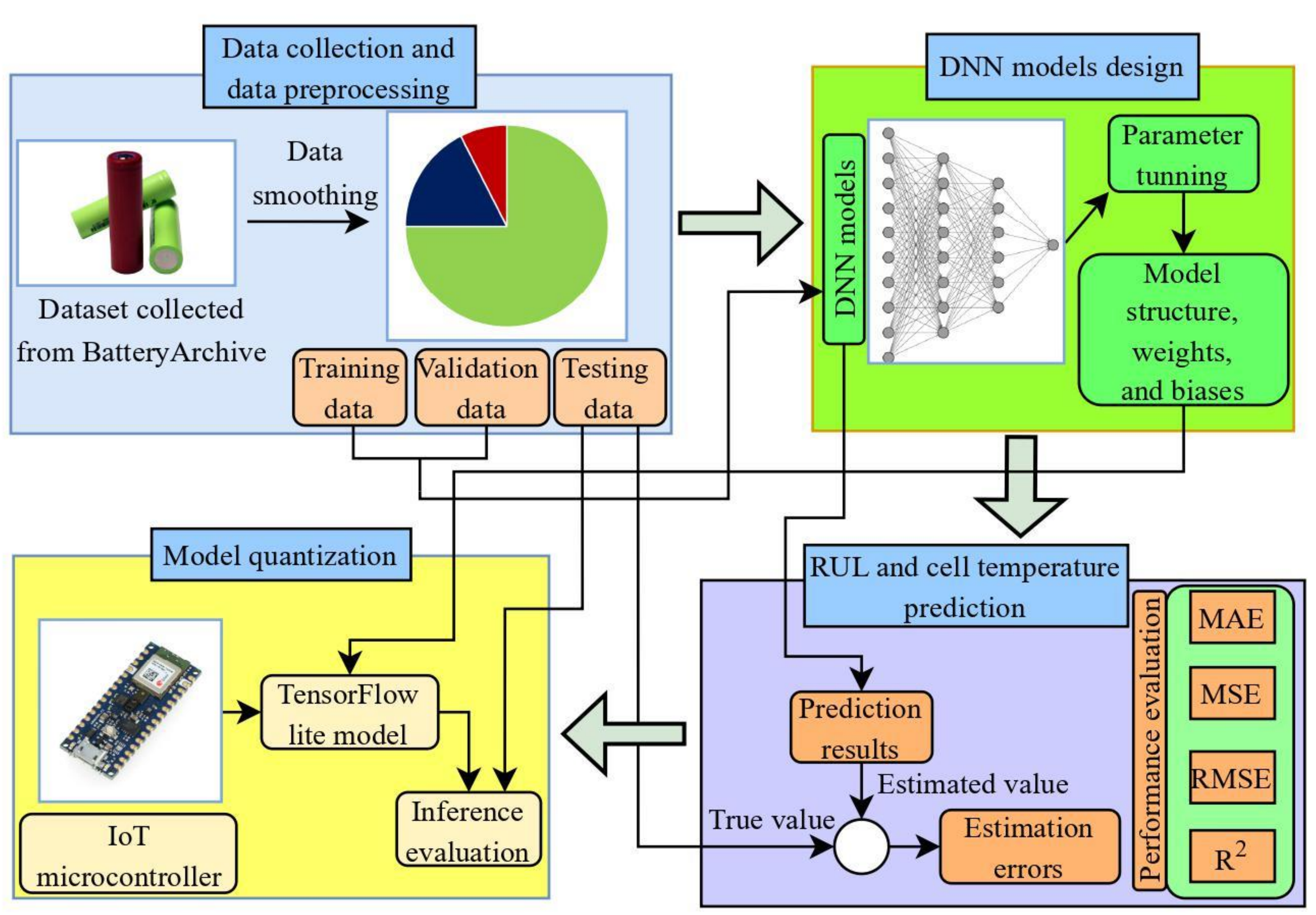
Model-based	Data-driven	Hybrid approaches
By using an algorithm of unscented Kalman filter (AUKF)	Dense Neural Network (DNN), and other machine learning models such as SVM and random forest	Combination of a signal processing and deep learning algorithm

TinyML techniques on Microcontroller Unit	
Battery State of Health (SoH)	Battery State of Charge (SoC)

Model Development and Testing Workflow

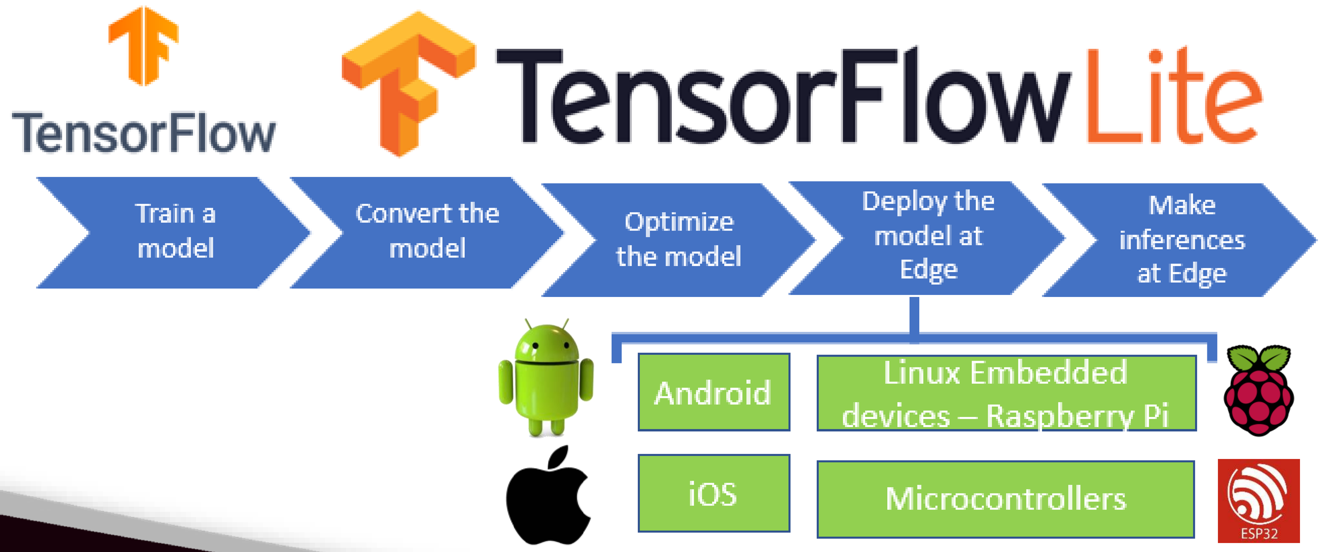
- Efficiency is critical for machine learning.
- CloudML targets accelerators like GPUs, while EdgeML focuses on portable devices like mobile phones. TinyML further pushes the efficiency boundary, enabling powerful ML models to run on ultra-low-power devices.
- TinyML has several key advantages. It enables machine learning using only a few hundred kilobytes of memory.
- There is a growing need for low-power, always-on, on-device AI [2].



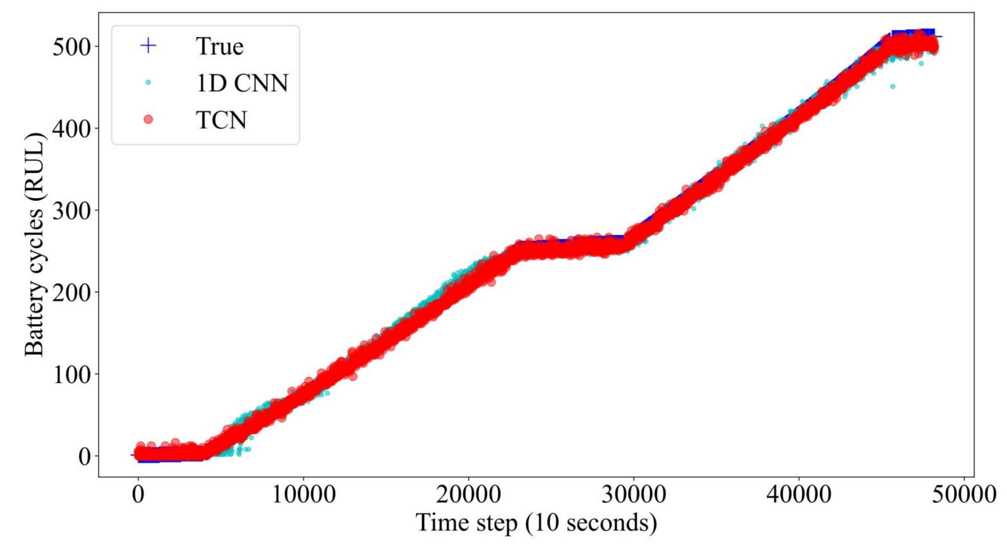


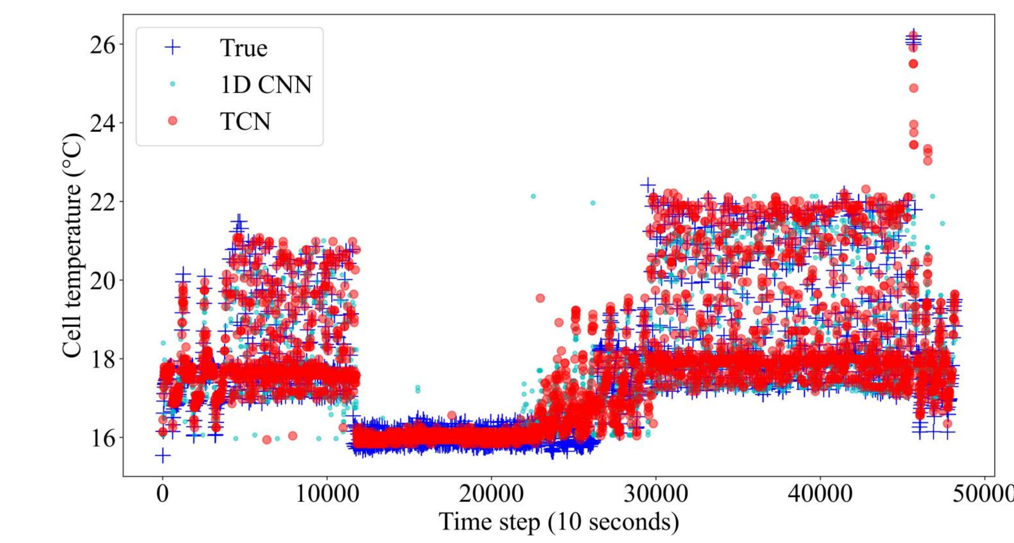
- Google's TensorFlow Lite (TFL) can convert the developed model into an optimized format that can be easily integrated into C/C++ applications run on the Arduino board and ESP32 board.
- The optimization technique is quantization, which is to convert the model from floating point 32-bit to 8-bit integer precision. And this will help reduce significantly the size of the model.
- The advantage of quantization is the model will be smaller in storage size and memory usage. However, the trade-off is performance degradation.

- We select two types of battery cells: Nickel Manganese Cobalt (NMC) and Nickel Cobalt Aluminum (NCA), and the cycling experiments used different values for temperature range and discharging current.
- The train and validation portions are used for deep learning models (CNN and TCN) development.
- The prediction results are evaluated in different error matrices.
- This step is done by simulations in Python and TensorFlow conducted on computers since the models have not been optimized/quantized for deployment to microcontrollers.
- The best-found deep learning model is then deployed on an IoT MCU by using TensorFlow lite and the inferencing results are obtained by URAT serial communication through the connection between the IoT device and the computer.



Performance Evaluation and Results





Models	TF MAE	TFLITE MAE	TFLITE_MICRO MAE
1D CNN (RUL)	5.91	6.16	6.173
1D CNN (Cell Temp.)	0.35	0.35	0.363
TCN (RUL)	0.64	1.88	4.213
TCN (Cell Temp.)	0.24	0.25	0.256

Models	TF model size (KB)	TFLITE model size (KB)	Reduction
1D CNN (RUL)	656	26.91	24x
1D CNN (Cell Temp.)	508	13.07	39x
TCN (RUL)	1208	40.59	30x
TCN (Cell Temp.)	1239	57.84	21x

Conclusion and Future Work

- Deep learning models are investigated for predicting battery cell RUL and temperature.
- The proposed TCN models are deployed on IoT device microcontrollers using tinyML and the has the best performance.
- We plan to develop similar deep machine learning models to predict multiple variables of interest to further reduce the memory capacity required to store and use for inference such models.

Reference

- [1] Y. Weng, W. Guan, and C. Ababei, "Prediction of Remaining Useful Life and Cell Temperature for Li-ion Batteries using TinyML," IEEE Inter. MWSCAS, 2024.
- [2] J. Lin, L. Zhu, W. -M. Chen, W. C. Wang, and S. Han, "Tiny Machine Learning: Progress and Futures [Feature]," in IEEE Circuits and Systems Magazine, 2023.

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