Adaptive State of Charge Estimation using Machine Learning Techniques for Temperature-Dependent Open Circuit Voltage on Embedded Systems

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ABSTRACT

For effective battery management, accurate estimation of state of charge (SOC) is essential. In order to estimate temperature-dependent SOC-OCV curves while avoiding the requirement for time-consuming testing, this research introduces a machine learning approach. The approach computes intermediate curves to generate a complete dataset using manufacturer-provided SOC-OCV curves at certain temperatures. This dataset is used to train a lightweight machine learning model for resource-constrained microcontrollers. The trained model can estimate the SOC-OCV curve in real time and at any temperature when implemented on an MCU. Without significant testing or large data storage, this compact machine learning technique provides faster, more accurate SOC estimate over a range of temperatures. The suggested approach demonstrates how machine learning has the ability to improve battery management systems while lowering computational complexity and memory needs.

1. Introduction

In recent years, batteries have become an essential component in various systems such as electric vehicles (EVs), drones, and portable electronic devices due to their high energy density and light weight [1]. An important factor in maintaining the longevity and efficiency of batteries is the effective management of the state of charge (SOC), which reflects the remaining capacity of the battery. An accurate SOC estimation is crucial in avoiding deep discharging or overcharging, ensuring battery safety and prolonging its lifetime [2]. One of the challenges in SOC estimation is the effect of temperature. Temperature influences battery dynamics, which in turn affects the open-circuit voltage (OCV), a parameter that has a distinct correlation with the SOC. Consequently, the SOC-OCV curve varies with temperature, complicating the task of SOC estimation. Traditional methods to tackle this issue often involve extensive testing at different temperatures, which can be time-consuming and costly [3].

With the advent of machine learning (ML), these complex systems can be modeled more accurately and quickly. ML techniques have been extensively used to predict various battery parameters with considerable success. However, the computational requirements of ML models can pose challenges when deployed on microcontrollers, which have limited resources.

This paper presents an approach to estimate temperature-dependent SOC-OCV curves using ML techniques without the need for comprehensive testing. The focus is on designing a lightweight ML model that is feasible for implementation on resource-constrained microcontrollers. Through the generation of a comprehensive dataset from manufacturer-provided SOC-OCV curves at certain temperatures, this paper demonstrates how machine learning can enhance the accuracy and efficiency of SOC estimation while reducing computational complexity and memory requirements.

2. Proposed approach

The proposed method combines the power of machine learning with the effectiveness of optimized resource management. To begin with, we gather SOC-OCV curves provided by manufacturers at certain fixed temperatures, and from this data, we compute intermediate curves to generate a comprehensive dataset. This unique dataset represents a wide range of temperature-dependent SOC-OCV curves, bypassing the need for extensive testing. Using this dataset, we train a machine learning model optimized for use on resource-constrained microcontrollers. This lightweight model, when implemented, is capable of estimating the SOC-OCV curve in real-time at any given temperature. It not only reduces the need for time-consuming testing and extensive data storage but also provides a faster, more accurate SOC estimation across a broad temperature range. In essence, our proposed method leverages machine learning to enhance battery management systems, making them more efficient, accurate, and adaptable to varying temperatures.

3. Training Neural Network

The dataset of SOC-OCV to train the model is taken from CALCE (Center for Advanced Life Cycle Engineering). The SOC-OCV data at three different temperatures is shown in Fig. 1.

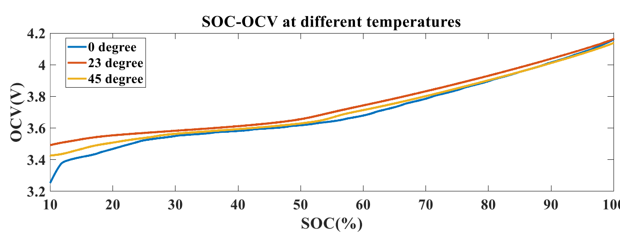

Fig.1 SOC-OCV data of battery at different temperatures

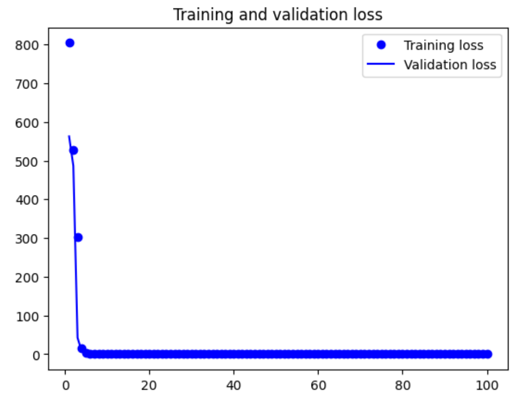

Fig.2 Training and validation loss

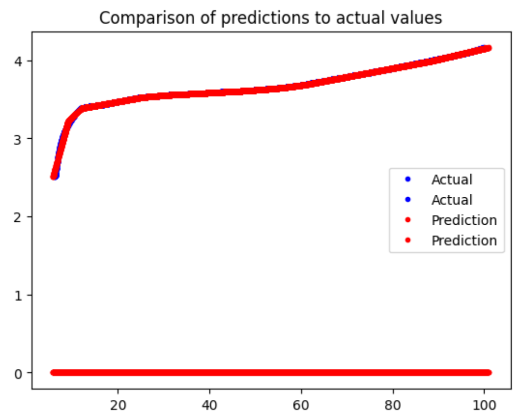

Fig.3 The comparison of actual and predicted values

The training is performed on Google Colab. The losses of trained model after the training are shown in Fig. 2. The losses are higher at start of training and these are reduced to lower values after several epochs. The comparison of actual and predicted values is shown in Figure 3.

4. Experiment and Results

The utilized trained model estimates the SOC over a single battery charge-discharge cycle. In this process, we use Coulomb counting and reset the SOC value following a half-hour rest period. To generate results, we import the model into the ESP32 microcontroller unit (MCU).

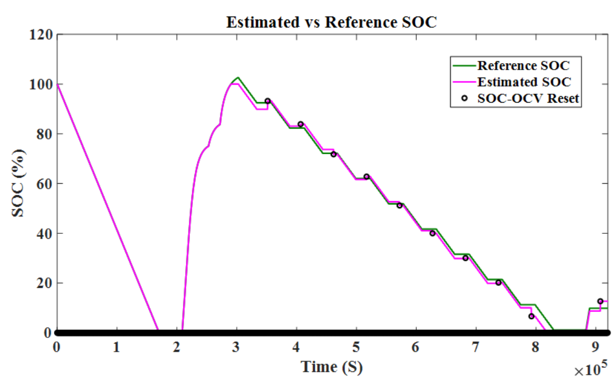

Fig.4 SOC Estimation results

The reset points are emphasized using circular symbols, facilitating a clear demonstration of SOC resetting, which is based on SOC-OCV values derived from the trained model. The results are shown in Fig. 4.

5. Conclusion

The research presented in this paper underscores the importance and effectiveness of machine learning for accurate SOC estimation, particularly in environments with fluctuating temperatures. By using manufacturer-provided SOC-OCV curves at certain temperatures and generating a comprehensive dataset, we were able to train a machine learning model tailored for resource-limited microcontrollers. This model provides real-time SOC-OCV estimation at any temperature, thereby improving battery management systems significantly. It alleviates the need for exhaustive testing, reduces memory requirements, and enhances the overall efficiency and adaptability of these systems. We firmly believe that our work can inspire further innovations in this field, ultimately leading to more sustainable and efficient battery-operated systems in the future.

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References

[1] Nykvist, B., & Nilsson, M. (2015). Rapidly falling costs of battery packs for electric vehicles. Nature Climate Change, 5(4), 329-332.

[2] Habiballah Rahimi-Eichi, Unnati Ojha, Federico Baronti and Mo-Yuen Chow. (2019). Battery management system: An overview of its application in the smart grid and electric vehicles. IEEE Industrial Electronics Magazine, 3(2), 4-16.

[3] Zhang, S. S., Xu, K., & Jow, T. R. (2003). The low temperature performance of Li-ion batteries. Journal of Power Sources, 115(1), 137-140.