Development of low-power algorithm to estimate the state of charge (SOC) using TinyML platform

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ABSTRACT

The computational complexity and power consumption of conventional State-of-Charge (SOC) estimation techniques make it difficult to estimate SOC accurately in environments with limited resources. This study uses TinyML, a platform created especially for devices with limited resources like microcontrollers, to develop low-power algorithm for SOC estimation. The proposed algorithms adaptively model battery behavior across varying operating conditions by utilizing machine learning techniques, improving accuracy and responsiveness. These lightweight models can easily be implemented on low-power devices thanks to the TinyML platform, which also drastically reduces computational overhead and energy usage. The proposed low-power SOC estimation algorithm have proven effective in experiments, achieving high accuracy while consuming little energy, making them suitable for resource-constrained applications.

1. Introduction

In resource-constrained environments where energy efficiency and optimal battery utilization are key considerations, accurate State-of-Charge (SOC) estimation is essential. SOC is the measurement of a battery's remaining energy capacity. It is possible to manage battery-powered systems more effectively, avoiding unexpected shutdowns, and making the best use of the energy that is available with accurate SOC estimation.
However, when used in environments with limited resources, conventional SOC estimation methods frequently run into problems. These restrictions are primarily brought on by how computationally complex and resource-intensive such techniques are. The available computing resources and energy budget are severely limited in devices with limited resources, such as microcontrollers or other low-power devices. Traditional SOC estimation methods may not be practical or effective in these circumstances because they call for extensive computations or complicated algorithms. This study suggests using low-power algorithm created especially for SOC estimation in environments with limited resources to address these issues. The algorithm can be effectively used on microcontrollers and other low-power devices by utilizing the TinyML platform, which was created for resource-constrained devices[1]. A variety of tools, libraries, and optimizations designed specifically for machine learning applications on devices with limited resources are offered by the TinyML platform[2]. It makes it possible to use lightweight models that use less energy and have fewer computational requirements. The proposed low-power algorithm for SOC estimation can be deployed successfully using the TinyML platform, benefiting from platform optimizations and reducing energy overhead[3].

2. Proposed Battery Charger Design

The ESP32 module is used to gather initial real-world data, such as temperature, current flow, and battery voltage. To make sure the model works in a variety of scenarios, it's critical to collect data that covers a wide range of operating conditions. To ensure that the collected data is in a format suitable for the LSTM model's training, the data is then preprocessed by appropriately normalizing and scaling it. The LSTM machine learning model has been selected for SOC estimation. LSTM have shown to be successful in processing sequential data, including time series data. Because of its architecture, it can recognize dependencies and patterns in the data and store information in memory cells that can do so for longer periods of time. The dynamics and temporal dependencies present in the battery behavior can be captured by LSTM in the context of SOC estimation.
The ESP32 module is used for the implementation of the LSTM model compression for SOC estimation as shown in Fig. 1. Quantization of the neural network, depicted in Fig.2, is involved for the model compression from 32 bit to 8 bit integer.

3. Results analysis

The dataset for experimental analysis is taken from the NASA online dataset[4]. The experimental findings confirm that the LSTM-based SOC estimation method on the low-power ESP32 module is effective as shown in Fig. 4. The method exhibits high accuracy, energy efficiency and low power consumption. These results confirm the potential of LSTM-based SOC estimation for accurate and effective SOC monitoring in resource-constrained environments, implemented with TinyML on low-power devices.

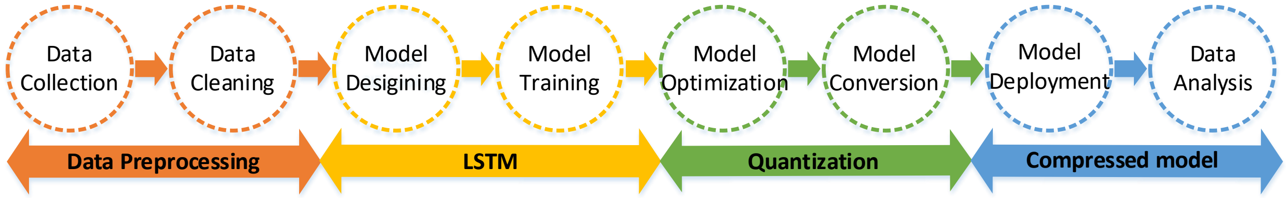

Fig.1 Block diagram of the proposed compression algorithm.

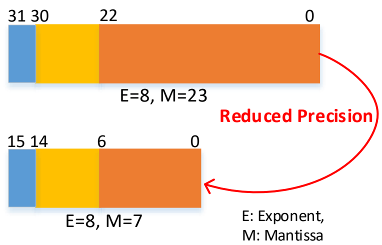

Fig. 2 Quantization involves mapping 32-bit floating-point weights to 16-bit fixed-point or 8-bit integer representation.

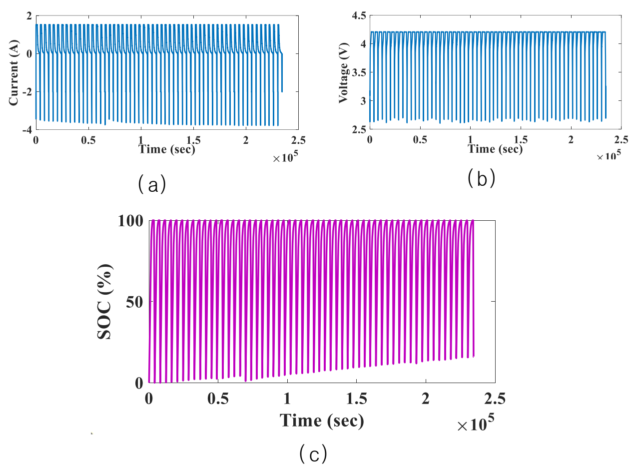

Fig.3 Dataset illustration containing Current, Voltage and SOC.

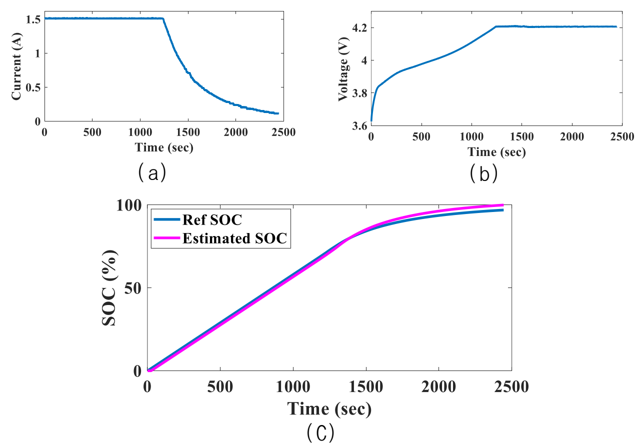

Fig. 4 SOC estimation results (a)Input current (b)input voltage, (c)SOC comparison results.

4. Conclusion

In order to estimate the low-power SOC on the ESP32 module, the research paper establishes the viability and effectiveness of using the TinyML platform and LSTM modeling. The results highlight the proposed methodology's high accuracy, robustness, energy efficiency, low power consumption, and real-time responsiveness. This study advances the field of SOC estimation in environments with limited resources and paves the way for future developments in improving battery performance and usage. The TinyML LSTM-based SOC estimation approach demonstrates its potential to raise the effectiveness and dependability of battery-powered systems in a variety of applications.

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