Integrating Real-Time Clock Synchronization with Kalman Filters to Improve Battery SOC Accuracy

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ABSTRACT

This work presents a novel method that combines real-time clock (RTC) synchronization with Kalman filtering to improve state-of-charge (SOC) estimation in battery management systems. The RTC module ensures accurate timing in each measurement and estimation step, addressing inaccuracies such as timer delay in microcontroller units. The Kalman filter adjusted in line enables more accurate SOC prediction, which significantly improves estimation precision. In our study, we detailed implementation methods that focus on power efficiency and computational optimization for microcontroller execution. As a result, the reliability and accuracy of SOC estimation beyond traditional methods have been greatly improved, and new criteria suitable for various battery technologies and conditions have been set. This contributes to optimizing battery usage and extending its lifetime in critical applications.

1. Introduction

Accurate SOC estimation is crucial for the effective management and operation of battery systems, particularly in applications where battery health directly impacts overall system reliability and performance[1]. Traditional SOC estimation methods typically rely on equivalent circuit models to simulate battery behavior and use Kalman filtering techniques to refine the estimates based on actual measurements[2]. These methods, however, are often compromised by the inherent limitations in the timing accuracy of microcontrollers used within battery management systems.

Microcontroller units (MCUs) are central to these systems, processing complex tasks that include real-time data acquisition, control, and communication. However, MCUs can suffer from timing inaccuracies due to oscillator jitter, which introduces variability in the time intervals used for sampling and estimation, and processing delays, which can postpone the execution of critical tasks[3]. Such timing inaccuracies can adversely affect the performance of both Kalman filters and equivalent circuit models. In Kalman filters, the precision of the time step Δt. Δt is essential for accurate prediction and update phases, as it directly influences the state transition matrix[4]. Similarly, equivalent circuit models, which rely on accurate time sequencing to correctly model the dynamic behaviors of the battery, are susceptible to errors if the timing of voltage and current measurements is not strictly controlled.

Recognizing these challenges, this study proposes an integrated approach using RTC synchronization to enhance the accuracy of SOC estimations. An RTC module provides a stable and accurate time base, mitigating the impact of MCU-related timing errors. By ensuring consistent and precise time intervals, the RTC module enables more reliable data sampling and processing, crucial for the effective application of Kalman filters and the accurate simulation of equivalent circuit models. This approach not only addresses the immediate needs of accurate SOC estimation but also sets a new standard in the resilience and efficiency of battery management systems.

2. Proposed approach

In this study, we introduce an enhanced method for SOC estimation in battery management systems by integrating an RTC with a Kalman filter, simulated using MATLAB Simulink. The RTC synchronization addresses timing inaccuracies typically encountered in microcontrollers, such as oscillator jitter and task-related delays, which can affect time-dependent data processing and accuracy.

Our methodology starts by synchronizing each measurement of voltage and current from the battery using an RTC module. This ensures that all data are timestamped accurately, providing a reliable base for the estimation processes. Utilizing an equivalent circuit model, the Kalman filter uses these precise timestamps to predict and update the battery's state more accurately. The RTC-enhanced time stamps allow the filter to handle the exact time intervals between measurements effectively. The proposed system is shown in Fig.1. Eq. (1) shows the dependence of equivalent circuit model terminal voltage estimation on time.

$$\frac{dV1}{dt} = \frac{i}{C1(SOC,T)} - \frac{V1}{R1(SOC,T)C1(SOC,T)} \tag{1}$$

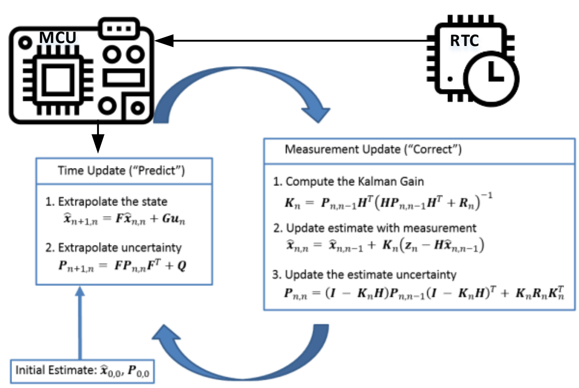

Fig.1 Proposed system using RTC with MCU.

3. Experiment and Results

In our experiment conducted in MATLAB Simulink, we evaluated the impact of timing inaccuracies on State of Charge (SOC) estimation by integrating a Real-Time Clock (RTC) with a Kalman filter. We simulated time data noise to reflect common microcontroller timing errors and compared SOC estimates derived from both noisy and original time data. The results demonstrated significant deviations in SOC estimates without RTC synchronization, highlighting the detrimental effects of timing inaccuracies. However, with RTC integration, the SOC estimates from noisy data closely aligned with the original, substantiating the effectiveness of precise timing in reducing errors and enhancing the reliability of SOC predictions in battery management systems.

To quantify this, we introduced a noise model that simulates the typical timing errors encountered in practical microcontroller applications. The SOC result with noise in time information is shown in Fig. 2, which compares the resultant SOC with the original SOC formed using accurate data and the Coulomb counting algorithm. Fig. 3 illustrates the error in SOC, which is around 4% due to the added noise in time information. These figures underscore the adverse impact of timing inaccuracies on SOC estimation and the necessity of incorporating RTC for accurate timekeeping.

Additionally, we performed a statistical analysis of the SOC estimation errors, revealing that the variance in SOC estimates was significantly reduced with the inclusion of the RTC. The results highlight the critical importance of accurate time information in SOC estimation algorithms. The addition of RTC in MCU systems can significantly improve the accuracy of SOC estimation results, making it a vital component in the development of robust battery management systems.

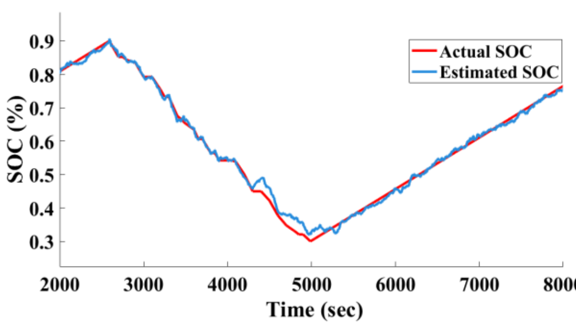

Fig.2 Actual SOC vs estimated SOC result.

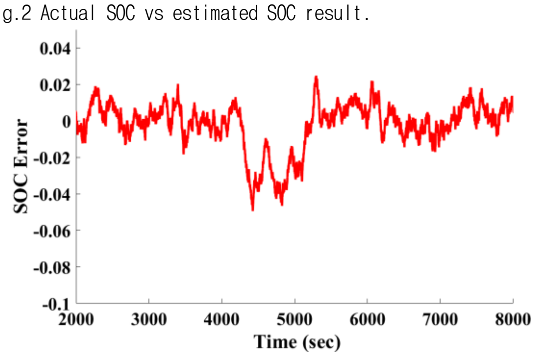

Fig 3. SOC error because of unstable time data.

4. 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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