Research on SOC Estimation Method of Ternary Lithium Battery Based on AEKF Algorithm

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ABSTRACT

This paper investigates the application of Extended Kalman Filter (EKF) and Adaptive Extended Kalman Filter (AEKF) techniques for State of Charge (SOC) estimation in lithium-ion batteries, a critical component in the battery management systems of electric vehicles. Accurate SOC estimation ensures battery reliability, longevity, and safety. However, the precision of SOC estimation is often compromised by sensor noise and bias, leading to inaccurate readings and inefficient battery usage. To address these challenges, we propose a robust estimation framework using EKF and AEKF, known for their efficacy in handling non-linear systems and measurement uncertainties. The research evaluates the performance of these advanced filtering techniques under various operating conditions, including temperature variations and aging effects. By comparing the estimation accuracy with traditional AH methods, the study highlights the superior capability of EKF and Adaptive EKF in dealing with the complexities of lithium-ion battery models.

1. Introduction

The environmental impact of technology, especially in the transportation sector, is seeing a surge in demand for eco-friendly solutions. Electric vehicles (EVs) that store energy in batteries and use them later, are becoming increasingly popular because of their potential to reduce emissions. Lithium-ion batteries are preferred because they are lightweight and have high electrochemical potential and energy density, allowing the EV to travel about 180-350 km. However, the efficiency and safety of these vehicles rely heavily on battery management systems (BMS), especially accurate state of charge (SOC) estimation. This paper attempts to address issues related to SOC estimation of lithium-ion batteries, especially sensor noise and bias, and changes in battery parameters.

SOC estimation is essential for effectively managing the battery system within the EV and is similar to the fuel gauge of an internal combustion engine vehicle [1]. However, unlike the fuel gauge, SOC depends on the electrode concentration of the lithium-ion and cannot be measured directly due to differences between the cells. This paper uses model-based estimation techniques, especially Extended Kalman Filtering (EKF), to improve SOC estimation under various operating conditions.

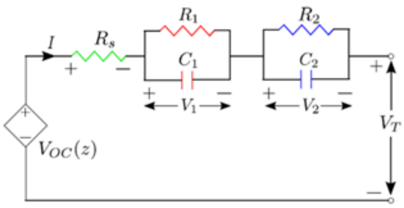
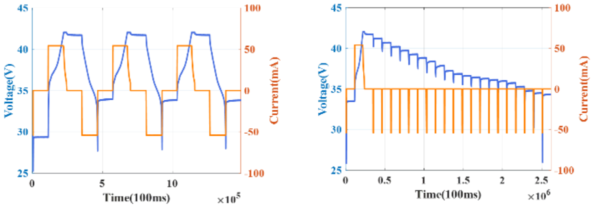


Fig. 1 2RC circuit battery model.



(a) (b)

Fig. 2 2RC circuit battery model. (a) Capacitance data, (b) OCV test data.

The main objective of this study is to develop and test SOC estimation algorithms using a secondary RC equivalent circuit model for lithium-ion batteries. Algorithms will be evaluated in various operating scenarios, including sensor noise and bias fluctuations, to evaluate their robustness and accuracy. This study aims to improve the reliability of SOC estimation of lithium-ion batteries used by electric vehicles, thereby enhancing safety and efficiency.

2. Method

The Extended Kalman Filter (EKF) is employed as a nonlinear estimator for the State of Charge (SOC) and sensor biases in lithium-ion batteries [2]. The implementation begins with developing a discrete-time state-space model derived from the continuous-time equivalent circuit model of the battery, as explained earlier. The EKF operates in two main steps: Prediction and Update. Mathematically, the implementation uses the following equations:

$$\hat{x}_{k|k-1} = f(\hat{x}_{k-1|k-1}, u_{k-1})$$

$$P_{k|k-1} = F_{k-1} P_{k-1|k-1} F_{k-1}^T + Q_{k-1} \tag{1}$$

$$K_k = P_{k|k-1}H_k^T(H_kP_{k|k-1}H_k^T+R_k)^{-1}$$

$$\hat{x}_{k|k} = \hat{x}_{k|k-1}+K_k(y_k-h(\hat{x}_{k|k-1},u_k))$$

$$P_{k|k} = (I-K_kH_k)P_{k|k-1} \tag{2}$$

When estimating SOC by the EKF algorithm, Taylor's formula expands the nonlinear system, and the higher-order term is removed to linearize the nonlinear system. Although the algorithm converts a nonlinear system into a linear system, SOC can be estimated by the Kalman filter method. Still, the effect of noise change on SOC estimation is ignored in SOC estimation. Therefore, the adaptive method is introduced into the EKF algorithm, which can automatically calculate the noise Q and R and adaptively change the value of Q and R in real-time by introducing a new interest matrix within a fixed window range. Can achieve noise estimation and correction, reduce the impact of noise on SOC estimation

3. Result and discussions

In the discharge of a lithium battery, the noise accumulation error will gradually increase the SOC estimation error because the EKF algorithm ignores the noise characteristics during discharge. At the same time, as the SOC of lithium batteries is further reduced, the nonlinearity of lithium batteries will be stronger. The EKF algorithm will further increase the estimation error because it ignores the higher-order term of the system. In the later stage of lithium battery discharge, under the superposition of two errors, the maximum error of the EKF algorithm is 0.27%. AEKF algorithm reduces the influence of noise on the estimation accuracy by correcting the noise in the process of SOC estimation of lithium batteries. From Fig 3, the AEKF algorithm can better estimate SOC and the maximum SOC estimation error is less than 0.2%

Fig. 4 The SOC estimation results of the AEKF and EKF algorithms are close to the real SOC at 0°C, the maximum error of both algorithms is 0.25%, and the results obtained at 0 degrees are almost the same. Fig. 5 At 40°C, the SOC estimation result of the AEKF algorithm is closer to the real SOC than the EKF algorithm, and the maximum error of the AEKF algorithm is 0.12%. The comparative results show that adding an adaptive method can effectively reduce the accumulation of SOC estimation errors and improve SOC estimation accuracy.

4. Conclusion

In this paper, the equivalent circuit model of the 2RC model seat battery is used to identify the parameters of the equivalent circuit model by OCV charging and discharging test. Modifying the model can effectively characterize the dynamic characteristics of battery charging and discharging. The simulation results show that the AEKF algorithm corrects noise by adaptive method, avoids accumulated error caused by EKF algorithm, reduces the estimation error in EKF algorithm, improves the estimation accuracy of lithium battery, and makes EKF algorithm more robust.

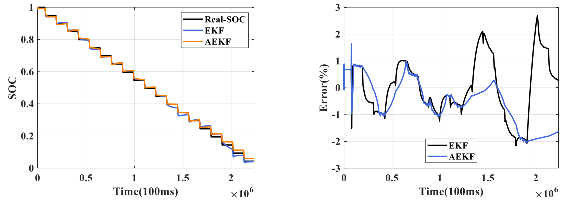


Fig. 3 25°C EKF vs. AEKF: SOC Estimates.

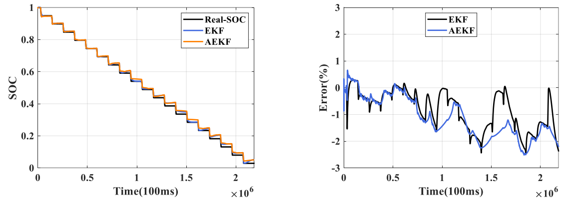


Fig. 4 0°C EKF vs AEKF: SOC Estimates.

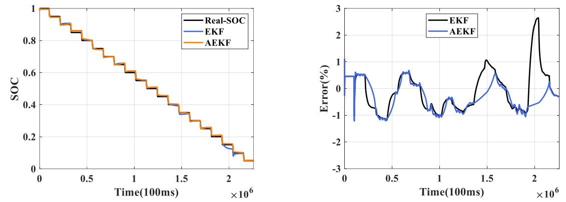


Fig. 5 40°C EKF vs AEKF: SOC Estimates.

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참 고 문 헌

[1] Zhou, J., Wang, S., Cao, W., Xie, Y., & Fernandez, C. (2023). Improved Backward Smoothing Square Root Cubature Kalman Filtering and Fractional Order—Battery Equivalent Modeling for Adaptive State of Charge Estimation of Lithium-Ion Batteries in Electric Vehicles. Energy Technology, 2300765.

[2] Lin, Q., Li, X., Tu, B., Cao, J., Zhang, M., & Xiang, J. (2023). Stable and Accurate Estimation of SOC Using eXogenous Kalman Filter for Lithium-Ion Batteries. Sensors, 23(1), 467.