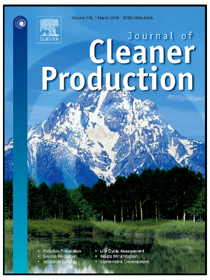
Accepted Manuscript



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PII:	S0959-6526(18)30267-1
DOI:	10.1016/j.jclepro.2018.01.236
Reference:	JCLP 11916
To appear in:	*Journal of Cleaner Production*
Received Date:	28 October 2017
Revised Date:	20 January 2018
Accepted Date:	29 January 2018

Please cite this article as: Shunli Wang, Carlos Fernandez, Mingjie Chen, Lu Wang, Jie Su, A novel safety anticipation estimation method for the aerial lithium-ion battery pack based on the real-time detection and filtering, *Journal of Cleaner Production* (2018), doi: 10.1016/j.jclepro.2018.01.236

A novel safety anticipation estimation method for the aerial lithium-ion battery pack based on the real-time detection and filtering

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Abstract – Lithium-ion battery packs have become increasingly important for power supply applications, in which the state of charge estimation and output voltage tracking should be very critical for the safety protection. A novel real-time estimation method is proposed by using the improved extended Kalman filtering algorithm together with the two-order resistance and capacitance circuit network battery model, aiming to solve its security protection issues. Experimental results show that this method can track the voltage signals effectively along with the real-time state estimation in the discharging and charging maintenance operation processes. The battery cell voltage detection accuracy is found to be 1.00mV and the pack voltage measurement error is less than 20.00mV. Meanwhile, the state of charge value can be estimated with a great accuracy of 2.00%, in which the state of balance parameter is considered for the internal connected battery cells. The developed experimental associated battery management system can be used for the working state monitoring in the aerial power supply application of the lithium-ion battery pack.

Keywords: lithium-ion battery pack; safety anticipation; state estimation; voltage track; Kalman filter

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1. Introduction

Lithium-Ion Batteries (LIB) are becoming increasingly popular as a source of energy in a dynamic power system applications, such as electric vehicles, renewable energy systems and satellite power supply systems, which is mainly due to its high energy density, low self-discharge rate and long cycle life advantages, compared with lead-acid, nickel-cadmium and other batteries. The technological developments in batteries are summarized by Hu *et al.* (2017). The LIB cells are assembled into battery pack with typically complex electrochemical devices. Therefore, the working state monitoring and security protection concerns of their working conditions are becoming the core issue for energy management applications of the aerial LIB pack. The accurate estimation of the remaining capacity is essential for optimizing the energy control system targeting at preventing it from over-charge/discharge risks, which is used to ensure its power safety during the service life.

The remaining capacity is characterized by the State of Charge (SOC) estimation. In order to meet the energy and power requirements of the aerial LIB pack, the battery pack usually contains several battery cells connected in series and parallel to provide adequate emergency power and energy. However, the safety issues limit its power applications and the real-time security protection is expected to be the core technology. The over-charge/discharge phenomenon has irreversibly damaged the LIB pack and reduced its performance and life cycle. A great number of researchers have investigated into different perspectives for battery applications as reported by Bruen *et al.* (2016), which promoted the LIB development in great progress for its dynamic and advanced power supply applications. The security issue is expected to be solved by carrying on real-time voltage detection together with the SOC estimation according to the relevant researches shown as follows. The combined in-situ and post-mortem investigation on the local permanent degradation is conducted by Bresciania *et al.* (2016) in a direct methanol fuel cell. In addition, a comprehensive review is proposed by Jaguemont *et al.* (2016) for the LIBs at cold temperatures. The fractional-order modeling and SOC estimation methods are studied by Zhang *et al.* (2016), in which the fractional-order modeling and optimal model parameter identification methods are proposed together with the fractional Kalman filter showing a good estimation performance. The investigation on internal short circuits of LIBs with a ceramic-coated separator is analysed by Kim *et al.* (2015) during the nail penetration process. The safety focused modelling is reported by Abadaa *et al.* (2016) for the LIBs. An advanced machine learning approach for lithium-ion battery state estimation is proposed by Hu *et al.* (2016), in which an advanced SOC estimator is developed *via* machine learning methodology. The SOC value, which reflects the remaining capacity of the battery, cannot be measured directly and should be obtained by indirect estimation methods. To the best of our knowledge this is the first manuscript to report a simple and versatile integration method, which provides a real-time detection and working state monitoring system that can be implemented in the battery management system (BMS) equipment.

The associated BMS equipment is developed on universal, intelligent, personalized, intimate interactive features and practicality. In addition, the safety and efficient energy management also involves security control, battery thermal management, critical data storage and analysis. The energy management method is reported by Lim *et al.* (2016) with automated mechanical transmission. The life cycle assessment method is analyzed by Zackrisson *et al.* (2016) for the lithium-air battery cells. The integration issues are investigated by Saw *et al.* (2016) for implanting the LIB into the battery pack. However, the real-time security monitoring problem is still not completely resolved, which needs effective solutions to a serious impact in the power application process for the security and safety effects. The voltage detection and real-time security forecasting research is conducted, aiming to solve the core issue in the development process of the Battery Management and Test System (BMTS) platform that is based on the improved Extended Kalman Filtering (EKF) algorithm. The SOC estimation of LIB is studied by Aung *et al.* (2016), in which the square root spherical Unscented Kalman Filtering (UKF) algorithm is used in nano-satellite. The understanding capacity fade is analyzed by Beattie *et al.* (2016) in silicon based electrodes for LIBs using three electrode