Novel SOC Monitoring Approach for Lithium Batteries

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Abstract. The key element in storage based systems remains the ability to monitor, control and optimise the performance of one or more modules of these batteries, the type of device performing this task is often referred to as a Battery Management System (BMS). A BMS is a basical units of electrical energy storage systems, a variety of already developed algorithms can be applied to define the main states of the battery, among others: state of charge (SOC), state of health (SOH) and state of functions (SOF) that allow real-time management of the batteries. All research in the field of Extended Kalman Filter (EKF) based BMS is based on bench-scale experiments using powerful softwares, such as MATLAB, for data processing and controllers such as dSPACE. So far, the constraint of computational power limitation is not really addressed in the majority of scientific papers dealing with this subject. This paper proposes an approach to implement an extended Kalman filter linked to a Coulomb counting method, this method called DCC-EKF will allow a better quality monitoring of the battery.

Keywords: Embedded System · Battery Management System · Extended Kalman Filter · Coulomb Counting.

1 Introduction

For battery-based systems, whether a hybrid vehicle, a solar powered device, or any other everyday electrical device (Robots, smartphone, laptop...), the battery is usually the only source of power they can access and rely on. As the importance of energy storage has continued to grow in recent years, researchers around the world have been developing more powerful and efficient batteries, both in terms of energy density and resistance. But developing the most powerful battery without optimising its management remains an act of little value, hence the power management of these batteries is so crucial and must be done properly. A good BMS is one that accurately estimates the SOC and SOH, basic approaches such as Open Circuit Voltage (OCV) and Coulomb Counting (CC) techniques, or slightly more complicated ones such as sliding mode [1], artificial intelligence [2] and Kalman filtering [3], are then used to try to estimate or predict the actual SOC of the battery.

As no specific accuracy requirement are defined, basic approaches are mostly used in smartphones and computers, they certainly use less time to calculate the state of charge, with a higher performance, but they do not produce an accurate calculation and generally give a misleading representation of it and lead to errors accumulation overtime. On the other hand, the complex methods, allow indeed to limit the error and the impact of uncertainties on the final result, but requires a computational power that is generally accomplished by the use of powerful controllers such as dSPACE. All research in the field of EKF-based BMS is based on bench-scale experiments using powerful software, such as MATLAB, for data processing. So far, the constraint of computational power limitation is not really addressed in the majority of scientific papers dealing with this subject.

This paper validates the possibility of applying an extended Kalman filter in an ATMEGA328P. This approach, called DCC-EKF, consists of performing an SOC prediction with an EKF function, and then sending the result to a Coulomb counting function for monitoring. The approach is implemented in a Battery Managment System designed from scratch.

2 Proposed BMS

For the BMS to provide optimal monitoring, it must operate in a noisy environment, it must be able to electrically disconnect the battery at any time, it must have the ability to monitor the state of each cell of the battery independently of the others, it must charge and discharge all the cells with the same rate, and in addition it must keep a constant monitoring on various parameters that can greatly influence the battery, such as cell temperature, cell terminal voltage and cell current [4, 5]. The general representation of the BMS is shown in Figure 1.

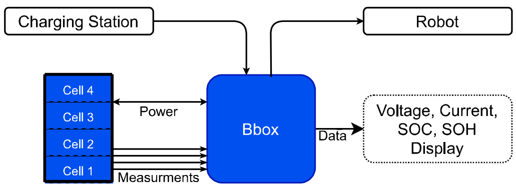

Fig. 1: General Representation of the *"Bbox"* Battery Managment System

The battery states are determined for each cell independently of the others by a specific microcontroller assigned to it, and works with the principle of Master/Slave communication by the means of I2C [6]. One microcontroller defined as a Master regroup the information and characteristic gathered from each other slaves microcontroller, analyses them and takes the main precautions to avoid any deep charge or discharge of the batteries, In order to keep a low sampling time, one slave microcontroller is assigned to two batteries, reaching a sampling time of the implemented algorithm of 0.085 seconds, all the three microcontrollers used are ATMEL's ATMEGA328P.

The master microcontroller is also connected to push buttons and an OLED screen to facilitate communication with the user. Power is supplied directly from the batteries, the voltage is stabilised and regulated for the BMS electronics by an step-down voltage regulator. The current flowing in and out the battery is measured with the use of an ACS-712 current measurment device. The voltage offered to the robot by the Bbox varies between 15 V and 11 V , no regulation is made keeping the regulation of the external voltage to the future users of the device.

3 Algorithm Description

The algorithm of this system consists mainly of two modes, the *initialisation mode* and the *on-mode*, both of which are highly dependent on each other. The use of an *initialisation mode* may seem strange at first sight for this type of product, but it is important to remember that the characteristics between cells are not uniform, neglecting this aspect can significantly reduce accuracy. *The initialisation mode* is responsible for the initialization of the battery capacity, in addition to activate or deactivate some features. As for the *On-mode*, the device shall begin the prediction of the actual SOC value for each cell using an EKF function described in Figure 2, and prohibits the passage of current to the robot for a period of approximately 3 minutes, the BMS electronics are still powered with a 70 mA current.

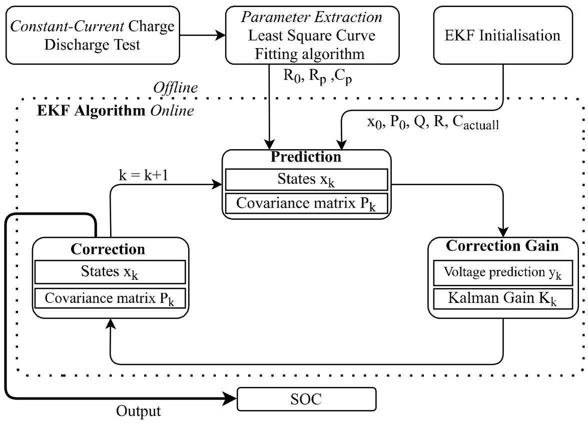

Fig. 2: Flow chart of the EKF function

Then, the predicted SOC is forwarded to the Coulomb counting function, which monitors the SOC using the following equation:

$$SOC(t_n) = SOC(t_{n-1}) + \frac{n_f}{C_{actual}} \int_{t_n}^{t_{n-1}} I \cdot dt \tag{1}$$

4 Results and Discussions

The BMS designed from scratch, implementing the new approach, can measure voltage with an accuracy of 100 mV and current with an accuracy of 40 mA and has an average energy efficiency of 94.38 %, and a total cost for one single prototype estimated at 32,21 €. The protection of the cell is provided by a S8254-A cell protection chip. The designed PCB is shown in Figure 3.

A test of the proposed EKF function was performed for correct and incorrect parameters in order to know its exact behaviour. For correct parameters (Figure 4), the EKF algorithm converges quickly and accurately to the SOC, an average of 3.81 % was recorded, in addition, this estimator is robust and resistant to external noise, a very important aspect for a BMS.

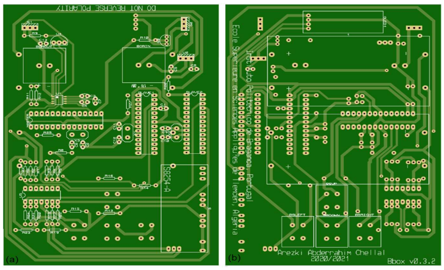

Fig. 3: Prototype printed circuit board. (a) componants view. (b) top view.

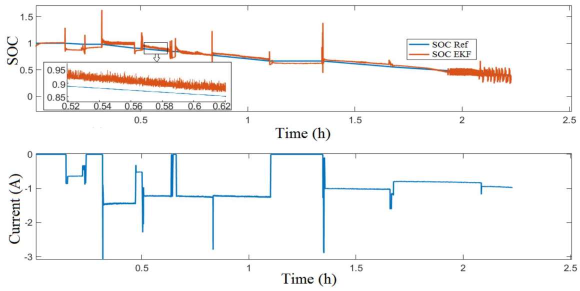

Fig. 4: Estimated and reference SOC comparison with the measured current

But for inaccurate parameters initialization, the algorithm converges to an incorrect value, the error increases as the difference between the actual value and the value of the implemented parameter increases. When the current stopped, the EKF converged rapidly, reaching a preliminary error of 10 % within a few sampling times, and then slowly converged to the reference SOC, after about 3 minutes it reached an error of less than 5 %. Figure 5 shows the results of wrong parametrization.

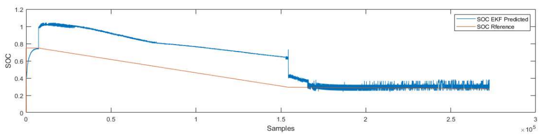

Fig. 5: Results of the EKF prediction with wrong parameters

5 Conclusion & Future Work

This study confirmed the possibility of implementing an EKF-based algorithm for SOC determination in an 8-bit microcontroller, taking advantage of its excellent behavior when the batteries are resting. This algorithm is implemented in a BMS designed meeting most of the constraints defined for such a device. The device is capable of reaching an accuracy of 5 %. The future development of this project will improve the prediction and introduction of an SOH monitoring, in addition to improving its energy efficiency and reducing its size.

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