Development of Low Cost, High-Performance Miniaturized Lithium-ion Battery Tester Using Raspberry Pi Zero

Phuong-Ha La, Hwi-Yeol Im and Sung-Jin Choi
School of Electrical Engineering, University of Ulsan, 44610, Korea

Abstract

This paper presents a low-cost portable lithium battery parameter measuring and estimating the solution. In this method, lithium battery characteristics are monitored during discharging and charging cycles. The battery profile is analyzed, and its key parameters are estimated by GNU Octave running on Raspberry Pi Zero, a mini computer. The proposed method can measure and estimate the battery parameters for SOC and DOD estimation with reasonable accuracy as well as portability features.

Keywords – Lithium-ion Battery; GNU Octave; Matlab; Raspberry Pi Zero; Battery Modeling; State of Charge (SOC); Depth-of-Discharge (DOD).

1. Introduction

The battery is the most popular energy storage for many applications around us, from a portable device, electric vehicle and renewable energy systems to DC microgrid. Among many kinds of batteries, lithium-ion battery has higher energy density, low self-discharge rate, long cycle life and doesn't have memory effect when compared with conventional battery type such as Ni-MH, Ni-Cd. However, management of lithium-ion battery also has some challenges due to its non-linear characteristics such as difficulties in balancing between cells and strong safety requirement to prevent overcharge or over-discharge.

In the market, there is some single-chip battery meter that is used for lithium-ion battery testing. Coulomb counting method is widely used for SOC estimation in this system because of its algorithm simplicity and low computational cost. However, its parameter accuracy is directly affected by sensing accuracy and an initial parameter of battery [3]. Therefore, this provides only low cost and low-performance solution.

To analyze lithium-ion battery characteristic in high accuracy, at minimum two kinds of special equipment is required: a data logger with memory is required for long-term measurement and recording of the charge/discharge cycles, PC with mathematical software packages or DSP (Digital Signal Processor) board for the estimation process. Several more advanced lithium-ion battery parameter estimation processing has been presented in the literature [1] - [2]. In these research, battery parameters are collected by the data logger and analyzed by Matlab software package under PC environment.

They adopted various estimation methods such as Kalman filter, MARS (multivariate adaptive regression splines) and Coulomb counting. The methods based on Kalman filter have limitations in sensitivity and stability. That is, the convergence of error, sensitive to the initial state estimation error and inaccurate Jacobian matrix estimation, if it is inaccurate could cause filter instability [1]. Another method based on computational intelligence using fuzzy logic and neural networks like MARS have high accuracy, but its computational cost is too high [2]. Anyway, all the high-performance methods make the cost too high and the low portability for the measurement system. In summary, Fig. 1 presents the relationship between performance vs the cost of the battery parameter estimation solutions.

To ensure the performance without sacrificing the cost and portability, we propose a measuring system based on Raspberry Pi Zero mini-computer running open source software GNU Octave. The proposed method shows low-cost, high performance and portability in miniaturized overall size.

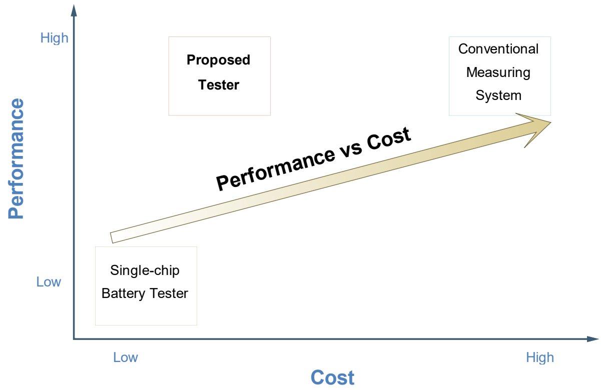

Fig. 1. Performance vs Cost of measuring systems

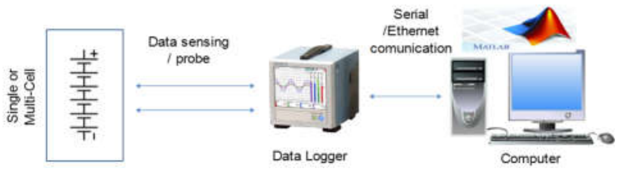

Fig. 2. Conventional testing environment.

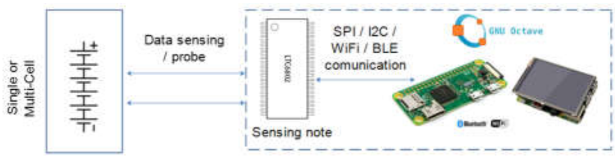

Fig. 3. Proposed tester.

2. Proposed Measuring Systems

To reduce the cost and raise the mobility, a low-cost, high-performance measuring system is proposed in Fig. 3. The battery data are measured by an LTC6802 module which is connected to an I2C communication bus with Raspberry Pi Zero (mini-computer). On Raspberry, the data are calculated by GNU Octave software. Based on the data and calculated result, GNU Octave sends the control command to ADC module to control the measuring process. All the process and result can be monitored in an LCD display module.

The Raspberry Pi Zero is an ATM card sized single-board computer. With a 1GHz single-core ARM 32bit processor, 512MB memory RAM, it can run Raspbian OS (Linux based OS) which can run GNU Octave. Raspberry Pi support both Wireless communication (WiFi, Bluetooth) and Wire communication (I2C, SPI, UART, Serial, USB, GPIO). The maximum power rating of Raspberry Pi when running is around 1.75W. Thus, Raspberry Pi will be matched with the portable, low energy and low-cost application.

GNU Octave is an open source clone software of Matlab featuring a high-level programming language, primarily intended for numerical computations. Thus, GNU Octave has enough function to replace Matlab in many application (data processing, instrument control, image processing, mapping, etc.). Due to function packages, the same M file used in Matlab can be used in Octave faster and has more computing efficiency.

The SOC and DOD of the battery are estimated by least squares estimation. The method of least squares is a standard approach in regression analysis to the approximate solution of overdetermined systems, i.e., sets of equations in which there are more equations than unknowns. "Least squares" means that the overall solution minimizes the sum of the squares of the residuals made in the results of every single equation. The best fit in the least-squares sense minimizes the sum of squared residuals (a residual being: the difference between an observed value, and the fitted value provided by a model). When the problem has substantial uncertainties in the independent variable (the x variable), then simple regression and least-squares methods have problems; in such cases, the methodology required for fitting errors in variables models may be considered instead of that for least squares [3]. In non-linear case, we can use numerical algorithms to find the value of the parameters ß that minimizes the objective:

$$\beta_j^{k+1} = \beta_j^k + \Delta\beta_j$$

Where a superscript k is an iteration number, and the vector of increments $\Delta\beta_j$ is called the shift vector. At each iteration the model may be linearized by approximation to a first-order Taylor series expansion about β_k:

$$f(x_i,\beta) = f^k(x_i,\beta) + \sum_j \frac{\partial f(x_i,\beta)}{\partial \beta_j}(\beta_j - \beta_j^k)$$
$$= f^k(x_i,\beta) + \sum_j J_{ij}\Delta\beta_j.$$

The Jacobian J is a function of constants, the independent variable, and the parameters, so it changes from one iteration to the next. The residuals are given by:

$$r_i = y_i - f^k(x_i,\beta) - \sum_{k=1}^{m} J_{ik}\Delta\beta_k = \Delta y_i - \sum_{j=1}^{m} J_{ij}\Delta\beta_j$$

To minimize the sum of squares of r_i, the gradient equation is set to zero and solved for $\Delta\beta_j$:

$$-2\sum_{i=1}^{n} J_{ij}\left(\Delta y_i - \sum_{k=1}^{m} J_{ik}\Delta\beta_k\right) = 0$$

Which, on rearrangement, become m simultaneous linear equations, the normal equations:

$$\sum_{i=1}^{n}\sum_{k=1}^{m} J_{ij}J_{ik}\Delta\beta_k = \sum_{i=1}^{n} J_{ij}\Delta y_i \ (j = 1, \dots, m)$$

The normal equations are written in matrix notation as:

$$(J^T J)\Delta\beta = J^T\Delta y$$

There are the defining equations of the Gauss-Newton algorithm.

3. Experiment Results

To validate the proposed method, an experiment is set up. In the experiment, the relationship equation between open circuit voltage and SOC is determined.

Open circuit voltage of Lithium battery is an important parameter in Battery modeling. When the battery is offline, we can estimate the SOC by using open circuit voltage.

In this experiment, a 18650 Li-ion Battery is fully charged before discharge with 0.1C in each 5% SOC or DOD. Between each discharging step, a long rest time is applied to allow it to reach the steady state. In steady state, the open circuit voltage of the battery is collected. On GNU Octave, Least Squares estimation is run to determine the equation. The experiment result is shown in Fig. 4.

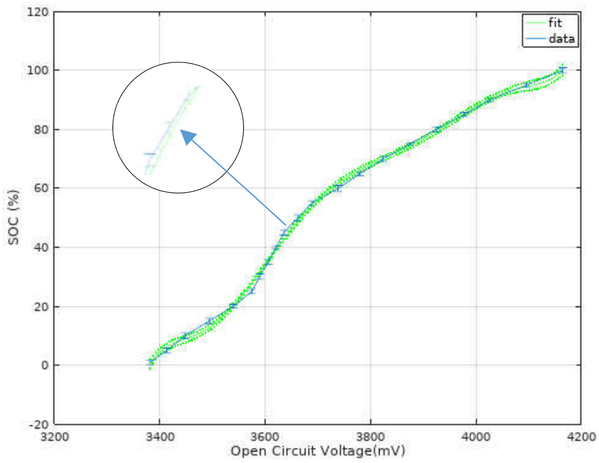

Fig. 4. Voc vs SOC and Least Squares estimation plot

The Least Squares equation (green line) is a seventh-order polynomial with $A_1=8.157\text{x}10^{-17}$; $A_2=-2.163\text{x}10^{-12}$; $A_3=2.456\text{x}10^{-8}$; $A_4 = 0.155\text{x}10^{-3}$; $A_5=0.5843$; $A_6=-1322.8$; $A_7=1.662\text{x}10^{6}$; $A_8=-8.939\text{x}10^{8}$; and v is open circuit voltage of battery:

$$SOC = A_1.v^7 + A_2.v^6 + A_3.v^5 + A_4.v^4 + A_5.v^3 + A_6.v^2 + A_7.v^1 + A_8$$

Due to the result above, the state of health or online state of charge of the battery is estimated by Kalman Filter or MARS method.

4. Conclusion

In this paper, a low-cost, high-performance battery measuring testing environment is proposed. By using mini-computer Raspberry Pi and open source GNU Octave software, the proposed measuring system can reduce the cost significantly without loss of performance. It is expected that, due to its miniaturized size and low power consumption, the proposed system is more suitable for applications that require portability such as battery tester for automation factory, input battery testing for BESS or battery testing for the electric vehicle in maintaining and repairing.

References

[1] Htet Aung, Kay Soon Low, Shu Ting Goh, *"State-of-charge Estimation of Lithium-ion Battery Using Square Root Spherical Unscented Kalman Filter (Sqrt-UKFST) in Nanosatellite,"* IEEE Transactions on Power Electronics, Vol. 30, No.9, September 2015

[2] J. C. A. Anton, P. J. G. Nieto, F. J. d. C. Juez, F. S. Lasheras, C. B. Viejo, and N. R. Gutierrez, *"Battery state-of-charge estimator using the MARS technique,"* IEEE Trans. Power Electron., vol. 28, pp. 3798–3805, Aug. 2013

[3] Jinho Choi. (2010). "*Optimal Combining and Detection – Statistical Signal Processing for Communications*". Swansea University, UK, pp. 49-77.