engineering proceedings

MDPI

Proceeding Paper

Design and Development of a Low-Cost and Compact Real-Time Monitoring Tool for Battery Life Calculation

Dimitrios Rimpas *, Vasilios A. Orfanos, Pavlos Chalkiadakis and Ioannis Christakis

Department of Electrical and Electronic Engineering, University of West Attica, P. Ralli & Thivon 250, 12244 Egaleo, Greece; vorfanos@uniwa.gr (V.A.O.); pchalk@uniwa.gr (P.C.); jchr@uniwa.gr (I.C.)
* Correspondence: drimpas@uniwa.gr

† Presented at the 10th International Electronic Conference on Sensors and Applications (ECSA-10), 15–30 November 2023; Available online: https://ecsa-10.sciforum.net/.

Abstract: Lithium- ion batteries are utilized everywhere from electronic equipment, smartphones and laptops to electric vehicles; however, certain disadvantages are inherited including high cost and low temperature range, caused by high currents. In this paper a compact and low-cost battery management system is presented which, can measure the voltage and current for both the battery and power supply. Two NTC thermistors, 10k and 100K Ohm each, are exploited for collecting battery temperature in two different spots of the socket for direct comparison and validation while an additional sensor measures external temperature and humidity. A charging socket is provided for charging the cell through an external source with dynamic voltage output to test the battery response. Finally, an Arduino compatible device is implemented in order to protect the battery from overcharging. This system is collecting parameters at a 10 s time rate and calculates precious parameters of the battery like state of charge (SoC), state of health (SoH) and state of power (SoP) Keeping the operation within a safe zone of 20–80% SoC maximizes longevity and ensures that it can provide even the maximum power to cover the load required, hence these three parameteres are considered as collerative. Afterwards, the collected data are being sent over Wi-Fi on the internet application server for real time monitoring, in an efficient, portable and low-cost setup.

Keywords: lithium; battery; monitoring; validation; arduino; aging; sensors

Citation: Rimpas, D.; Orfanos, V.A.; Chalkiadakis, P.; Christakis, I. Design and Development of a Low-Cost and Compact Real-Time Monitoring Tool for Battery Life Calculation. *Eng. Proc.* **2023**, *56*, x. https://doi.org/10.3390/xxxxx

Academic Editor(s): Name

Published: 15 November 2023

1. Introduction

Lithium batteries are the main power source for all electronic components that are widely used on a daily basis, such as portable computers, smartphones and electric vehicles. They consist of four main components: anode, cathode, electrolyte and separator [1]. During discharge, lithium ions flow from the anode to the cathode and vice versa while charging. The electrolyte helps this energy trade and the separator protects the two parts of the battery from internal short circuits [2]. Compared to previous technologies like lead acid they can provide greater energy density with more robust and compact sizing, actively enhancing their adoption at every modern device as storage or renewable plants or electric vehicles which is the latest trend towards a greener environment [3,4].

However, all lithium-ion technologies inherit several flaws. The high temperature caused by fast charging or discharging at any situation, creates lithium dendrite, electrolyte decomposition or even cracking inside the cells leading to total breakdown [5]. This aspect inquires the need for a monitoring system that is constantly collecting important values like its capacity, voltage, the current drawn or applied to the battery, and most importantly temperatures at the electrodes and of the casing externally [6].

In order to determine the status and protect the battery for any damage, there are 4 specific values that can be calculated which include [7,8]:

- State of Charge (SoC)

- State of Health (SoH)
- State of Power (SoP) and
- Depth of Discharge (DoD)

SoC describes the battery current charge compared to full, SoH reflects the current capacity after any life cycles and SoP is defined as the peak power that the battery can supply at a certain time period. A variable that can be easily monitored and provide information about battery use and user behavior is Depth of Discharge, which shows the usage percentage at each case, for example 100% to 40% equals to 60% DoD. Previous research concluded, points out that high depth of discharge with low SoC at end of each use stresses the cells and can lead to severe damage and low State of health [9,10].

It is visible that these 4 parameters are crucial for the battery status diagnosis. Low state of charge (below 20%) associated with high depth of discharge signifies high battery stress. If the temperature of the cells overcomes the safe limit at 40° Celsius, it will cause lithium deposition on the cathode leading to less available lithium flowing from the anode to cathode so SoH is lowered [11]. Additionally, if battery health (SoH) is limited, it will be strained to cover the energy demand for the nominal time or any peak loads required, turning to safe mode or even total breakdown [12]. High SoC for long periods can also damage the battery as being close to full charge adds excessive pressure to the electrolyte and the separator [13,14]. Hence a Battery management system protecting the battery with the nominal operational conditions is vivid for a safe and uninterrupted functioning.

The goal of this paper is to suggest a simple, compact and user-friendly setup based on an Arduino compatible device. A typical 18,650 battery is employed as the key element for testing with the addition of a current and a voltage sensor for the respective values collection. Moreover, a set of NTC thermistors with different ohmic grades (10k and 100k Ohms) collect the battery temperature at the electrode end while the external temperature and humidity are also collected at a 10 s time frame like the other parameters. Then all values are transferred to an internet application server with Wi-Fi for real time monitoring and further processing.

2. Materials and Methods

2.1. Experimental Layout

According to the experiment requirements, a battery tester board is developed to monitor and transfer the data at the central application host. The board includes various components, all deployed within an Arduino compatible device, which can be programmed using the Arduino IDE user friendly interface for further adjustments. The TTGO@ESP32 is selected as the main processing unit due to its high affordability and processing power with low power consumption and size. It includes 25 I/O (Inputs/Outputs) and analog ports, with I2C (Inter-Integrated Circuit) and SPI (Serial Peripheral Interface) capable of functioning as a communication interface supporting Wi-Fi and LoRa protocols. In addition, the voltage reading of the analog ports is supported by 4095 step positions, resulting in higher measurement accuracy.

The layout includes two current sensors (ACS712-5A), which can measure up to 5A corresponding to the analog output 185 mV/Amp, while the sensitivity is set and calibrated by the built in potentiometer. A set of coupled resistors (100KΩ) are implemented as the voltage divider to monitor both charging and discharging voltage sequences. For the battery temperature value, two thermistors (NTC) with distinct resistances, 10 kΩ and 100 kΩ, were used for further validation regarding the accuracy of the measurement. In addition, the environmental temperature and humidity values were provided by a single and calibrated barometric sensor (GY-213V-HTU21D).

The battery selected is a NiteCore NL1823 Li-Ion with a capacity of 2.300 mAh and nominal voltage of 3.7 Volts, placed within a socket soldered into the board. This module can be charged internally via a DC adapter or a photovoltaic (PV) panel with a supply up to 6 volts. An additional plug for external load is provided for testing the battery performance. At the working state, all measurements from the battery are collected every 10 s as a time frame. Then the board sends the measurements (voltage, current, temperature and humidity) to the internet application server over Wi-Fi using HTTP POST messages. The application platform includes a database for storing data and a web server (Grafana UI) for the data visualization or reception. Figure 1 below displays the layout of the circuit including the CPU, sensors, battery, DC Supply plug and the load output.

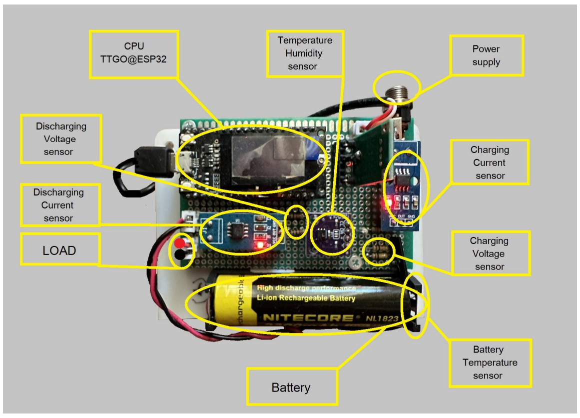


Figure 1. Layout circuit including the processing unit, sensors and lithium battery.

2.2. Calculation of Selected Parameters

The collected values from the circuit, are used for the calculation of the previously mentioned parameters (SoC, SoH, SoP and DoD), which significance isstated previously in introduction. According to literature [10–12] there is a variety of complex equations to get these values. For this experiment the following rules are obliged:

- SoC equals to the ratio of current capacity divided by the nominal value;
- SoH is defined as the maximum voltage of the battery divided by nominal;
- SoP refers to the maximum current that can be drawn from the battery and
- DoD is calculated manually depending on the SoC before and after charging;

Capacity can be identified by subtracting current drawn from nominal and multiplying it with hours to convert in Ampere-hours. To simplify the calculations, the state of voltage (SoV) term is utilized as a SoC alternative that is identical for battery status monitoring [13]. Therefore, the following equations are utilized to calculate these parameters:

For State of Charge:

$$\text{SoC} = \frac{C}{C_{RATED}} \tag{1}$$

For State of Health:

$$\text{SoH} = \frac{V_{MAX}}{V_{RATED}} \tag{2}$$

For State of Power:

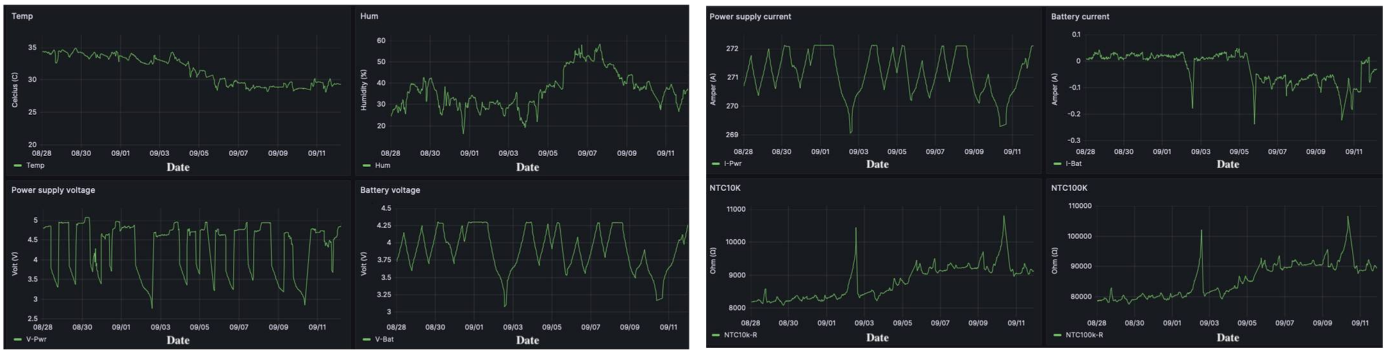
$$\text{SoP} = I_{MAX} * \frac{dT}{dt} \tag{3}$$

For Depth of Discharge:

$$\text{DoD} = \text{SoC}' - \text{SoC} \tag{4}$$

3. Results and Discussion

The values monitored were collected and presented in Figure 2 at Grafana Interface. Constant monitoring is available through this free web application and data can be extracted for any specific time frame, adding better control and direct data comparison.



(**a**) (**b**)

Figure 2. The eight values monitored and imprinted through Grafana Interface. Specifically, the following parameters are available: (**a**) Humidity, Ambient temperature, Supply Voltage and current and (**b**) Battery voltage and amperage with the output of the NTC thermistors.

Total measurements gathered are 30,000, spread over a month period. The comparison between the NTC thermistors to validate the accuracy was fulfilled and presented in Figure 3. The results show that both NTCs, 10k and 100k (after value correction for the first one) provide the same sensitivity in temperature changes and can be utilized for his work.

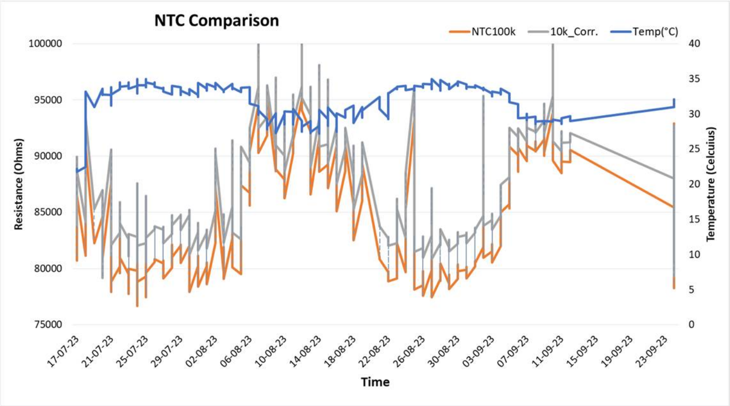


Figure 3. The comparison between the thermistors reveals identical accuracy after value correction.

Testing is based on the experiment ambient temperature, located in the province of Peristeri in Athens, Greece. As mentioned before, temperature has a key factor in battery performance. As the power voltage is increasing, battery voltage is enhanced but not in a linear way, due to the increased temperature, affecting its internal resistance, which can be seen to the second graph very clearly. The temperature of the battery is highly affected from the voltage applied and is calculated via the 100k NTC datasheet [15]. As resistance increases, lithium ion flow is limited both at charging or discharing phases, and overheating due to high current or ambient temperature causes dendrites forming at the electrodes so less lithium ions are available to flow and capacity is limited [5–7] In this testing, temperature remains within operation limits of the cells. After measurement 145, supply voltage was limited for providing further protection. In the graph a linear decrease can be seen in both voltages as the source is disconnected, with simultaneous increase in both temperatures. It can then reach the maximum point when the source voltage is reapplied. Figure 4 below imprints this sequence.

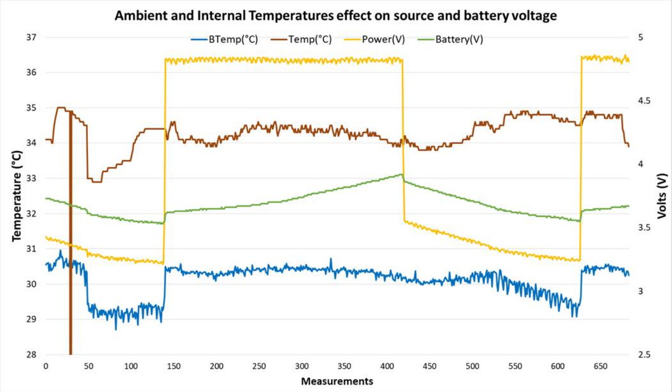


Figure 4. Temperatures role in battery and supply voltage variation influenced by power voltage.

The variation of battery current corresponding to external and internal temperatures are displayed in Figure 5. The current and voltage fluctuations are similar while the ambient temperature and current variations are too modest to provide any major outcomes.

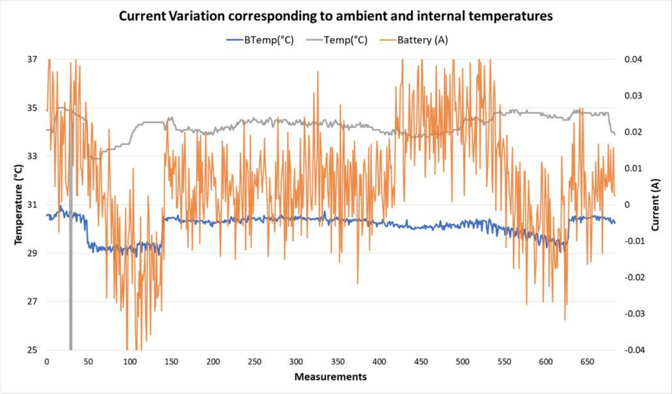


Figure 5. Current fluctuations due to variation onAmbient and internal temperatures.

The next step is to calculate the battery parameters mentioned in Section 2.2, hence the results summarized in Table 1. State of Charge was maintained at 40–80% hence a DoD of 40% If DoD is increased and battery is dropped below 20% charge, it is suspectible to lithium deposition, causing reduction in SoH [9]. By not keeping the battery at 100% charge, state of health decreased only by 0.1% after 50 cycles. Batteries are manufactured with over 100% available SoH, typically 102–110% so the drop is not visible in Table 1. State of Power can reach 6x the battery capacity, with a small decrease after testing, as battery chemically ages. A significant factor was the high ambient temperature, typically 30–35° Celcius due to summer conditions. So, no major stress at the batteries was applied.

Table 1. Battery parameters calculated before and after testing.

Parameter	Before Testing	After Testing
SoC	90%	60%
SoH	100%	100%
SoP	15 A	14.8 A
DoD[1]	40%	40%

[1] Typical DoD range achievable due to layout limitations.

4. Conclusions

This work presented a compact, affordable and customizable layout of lithium battery monitoring through a web app monitoring platform. Certain values like ambient and internal temperatures were gathered to calculate important values for the battery like State of Charge and State of Health. The results show that battery stress is mainly affected by battery current and supply voltage that raises internal temperature causing dendrites at the battery electrodes, reducing total capacity. In this work, it is suggested that SoC should be maintained with an optimal range (20–80%), while low DoD and operating current lead to major cells longevity as SoH is decreased by only 0.1% after 50 cycles while maintained at safe operating conditions. Future work involves an advanced software tool for calculating more parameters like State of Life and a bigger setup to be tested in EV modules, mainly focused on battery stress verification with an addition of more sensors and the ability to handle increased currents required within the safe temperature zone.

Author Contributions: Conceptualization, D.R. and I.C.; methodology, D.R.; software, V.A.O.; validation, I.C. and V.A.O.; formal analysis, V.A.O.; investigation, P.C. and V.A.O.; resources, I.C.; data curation, D.R.; writing—original draft preparation, D.R.; writing—review and editing, D.R. and I.C.; visualization, I.C.; supervision, V.A.O.; project administration, I.C.; funding acquisition, D.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement:

Informed Consent Statement:

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Scrosati: B.; Garche, J. Lithium Batteries: Status, Prospects and Future. *J. Power Sources* **2010**, *195*, 2419–2430. https://doi.org/10.1016/j.jpowsour.2009.11.048.
2. Manthiram, A. A Reflection on Lithium-Ion Battery Cathode Chemistry. *Nat. Commun.* **2020**, *11*, 1550. https://doi.org/10.1038/s41467-020-15355-0.
3. Rahimi, M. Lithium-Ion Batteries: Latest Advances and Prospects. *Batteries* **2021**, *7*, 8. https://doi.org/10.3390/batteries7010008.
4. Rimpas, D.; Kaminaris, S.D.; Aldarraji, I.; Piromalis, D.; Vokas, G.; Papageorgas, P.G.; Tsaramirsis, G. Energy Management and Storage Systems on Electric Vehicles: A Comprehensive Review. *Mater. Today Proc.* **2022**, *61*, 813–819. https://doi.org/10.1016/j.matpr.2021.08.352.
5. Yao, L.; Xu, S.; Tang, A.; Zhou, F.; Hou, J.; Xiao, Y.; Fu, Z. A Review of Lithium-Ion Battery State of Health Estimation and Prediction Methods. *World Electr. Veh. J.* **2021**, *12*, 113. https://doi.org/10.3390/wevj12030113.
6. Zhou, X.; Han, X.; Wang, Y.; Lu, L.; Ouyang, M. A Data-Driven LiFePO4 Battery Capacity Estimation Method Based on Cloud Charging Data from Electric Vehicles. *Batteries* **2023**, *9*, 181. https://doi.org/10.3390/batteries9030181.
7. Gauthier, R.; Luscombe, A.; Bond, T.; Bauer, M.; Johnson, M.; Harlow, J.; Louli, A.; Dahn, J.R. How Do Depth of Discharge, C-Rate and Calendar Age Affect Capacity Retention, Impedance Growth, the Electrodes, and the Electrolyte in Li-Ion Cells? *J. Electrochem. Soc.* **2022**. https://doi.org/10.1149/1945-7111/ac4b82.
8. Reshma, P.; Manohar, V.J. Collaborative Evaluation of SoC, SoP and SoH of Lithium-Ion Battery in an Electric Bus through Improved Remora Optimization Algorithm and Dual Adaptive Kalman Filtering Algorithm. *J. Energy Storage* **2023**, *68*, 107573. https://doi.org/10.1016/j.est.2023.107573.
9. Rimpas, D.; Kiatipis, A. Charging Strategy Effect on Lithium Polymer Battery Capacity: A Case Study. *Int. J. Energy Environ.* **2020**, 107–118.
10. Andrenacci, N.; Vellucci, F.; Sglavo, V. The Battery Life Estimation of a Battery under Different Stress Conditions. *Batteries* **2021**, *7*, 88. https://doi.org/10.3390/batteries7040088.
11. Zia, M.F.; Elbouchikhi, E.; Benbouzid, M. Optimal Operational Planning of Scalable DC Microgrid with Demand Response, Islanding, and Battery Degradation Cost Considerations. *Appl. Energy* **2019**, *237*, 695–707. https://doi.org/10.1016/j.apenergy.2019.01.040.
12. Kostopoulos, E.D.; Spyropoulos, G.C.; Kaldellis, J.K. Real-World Study for the Optimal Charging of Electric Vehicles. *Energy Rep.* **2020**, *6*, 418–426. https://doi.org/10.1016/j.egyr.2019.12.008.
13. Wikner, E.; Thiringer, T. Extending Battery Lifetime by Avoiding High SOC. *Appl. Sci.* **2018**, *8*, 1825. https://doi.org/10.3390/app8101825.
14. How, D.N.T.; Hannan, M.A.; Hossain Lipu, M.S.; Ker, P.J. State of Charge Estimation for Lithium-Ion Batteries Using Model-Based and Data-Driven Methods: A Review. *IEEE Access* **2019**, *7*, 136116–136136. https://doi.org/10.1109/ACCESS.2019.2942213.

15. NTC100K Datasheet. Available online: https://datasheetspdf.com/pdf-file/944190/Danfoss/NTC100K/1 (accessed on 27 September 2023).