International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 46 No. 2 September 2024, pp. 527-536

Arduino-Based Low-Cost Battery Capacity Measurement Tool

Ranto RAJERINANDRIANINA, Eulalie RAFANJANIRINA,

J. Z. Tigana MANDIMBY, Salohy Bruno Paul Micky TOKINIRINA, Zely Arivelo RANDRIAMANANTANY
Laboratory of Thermodynamics, Thermal Engineering, and Combustion (LTTC), University of Antananarivo, PB 566, Antananarivo 101, Madagascar
Corresponding Author: Eulalie RAFANJANIRINA; rafanjanirina@yahoo.fr

Abstract— This work presents the development of a new high-precision coulomb counting-based capacimeter. The goal was to provide a reliable, low-cost, portable, accessible, and user-friendly tool for non-professionals to accurately assess battery capacity. Results demonstrate that our slow discharge capacimeter offers precise and reproducible measurements of Li-ion battery capacity. This advancement opens new avenues for optimizing energy systems and selecting high-performance batteries.

Keywords— Arduino; Capacimeter; Battery; Microcontroller; Diagnostic; Low-Cost

I. INTRODUCTION

Batteries are ubiquitous in our lives ([3], [4], [11]) but often underperform compared to manufacturers' claims [6]. This gap impacts device lifespan, user satisfaction, and the environment. Given the growing importance of batteries, accurate performance assessment is critical. We have developed an innovative, affordable, and user-friendly device to measure battery capacity and voltage precisely. Our device offers a reliable and efficient solution to evaluate battery performance. This study details the device's operation, presents test results, and discusses potential improvements.

Batteries are essential electrochemical devices that convert chemical energy into electrical energy ([11], [12]). They play a pivotal role in a wide range of applications, including mobile phones, laptops, electric vehicles, and many others [5]. To function optimally in their respective applications, batteries must deliver a specific voltage and capacity that meet the requirements of the devices they power ([1], [8]).

However, it is often challenging to ensure that purchased batteries actually possess the technical characteristics promised by manufacturers. Studies have revealed that some batteries available on the market do not meet the advertised performance, leading to a significantly shorter lifespan than users expect [5]. This raises concerns about the reliability of the information provided about these products.

Although tools exist for testing batteries, their reliability and accuracy are often questioned. For example, professional testing equipment, while robust, has significant drawbacks: it is expensive and requires specialized technical knowledge to operate. Some advanced techniques, such as electrical impedance analysis and X-ray tomography, hold great potential ([2], [7], [9], [10], [13]). However, their complexity and high cost make them impractical for most users. This highlights the urgent need to develop an accessible and simple device to verify the actual performance of batteries, while remaining usable by a non-professional audience.

II. MATERIALS AND METHOD

A. General Context

Battery capacity, a critical parameter for evaluating battery performance, is defined as the amount of electric charge it can deliver to a load. To determine this capacity, it is necessary to subject the battery to a complete discharge and measure the amount of electric

International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 46 No. 2 September 2024, pp. 527-536

charge delivered. The classical method, based on the use of analog measurement instruments, is relatively simple but prone to measurement errors.

To improve the accuracy and reproducibility of measurements, we propose a method based on the use of a microcontroller. The microcontroller allows real-time monitoring of battery parameters (voltage, current) and calculation of capacity with high precision. Moreover, the automation of the measurement process reduces the risk of human error.

B. Electrical properties of a battery

The three main characteristics of a battery are:

- Voltage: When fully charged, a battery's voltage is about 20% higher than its working voltage. To charge a battery, a voltage higher than the system voltage is required. This voltage is called the charging voltage. The charging voltage of a battery depends on the type of generator, for example, for a 12V battery, it is equal to 14.4V.
- Capacity: This represents the amount of electric charge it can store. It is expressed in Coulombs (C) or Ampere-hours (Ah). 1Ah = 3600C. Capacity is often expressed relative to mass (mass capacity) or volume (volumetric capacity).
- Energy density: This is the amount of energy stored per unit mass or volume. It is expressed in Wh/kg or Wh/L.

C. Required materials

To build an Arduino-controlled capacitance meter, the following materials are necessary.

1. Microcontroller

A microcontroller is a small, low-power computer on a single integrated circuit designed to control specific operations in an embedded system. It typically includes a processor core, memory for program storage and data, input/output peripherals, and timers. Microcontrollers are widely used in applications where cost, size, and power consumption are critical factors.

2. Arduino Uno

The Arduino Uno is a popular open-source microcontroller board based on the ATmega328P microcontroller. It provides a simple and affordable platform for learning electronics and building interactive projects. The board features a variety of input and output pins, allowing for easy connection to sensors, actuators, and other electronic components. The Uno board is powered by a USB (Universal Serial Bus) connection or an external power supply and can be programmed using the Arduino IDE (Integrated Development Environment).

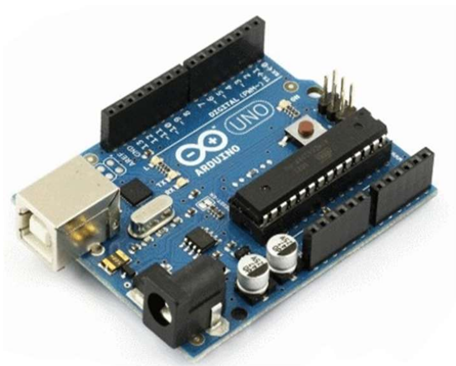


Fig.1 Arduino Uno Development Board

3. ATmega1284

The ATmega1284 is an 8-bit AVR microcontroller from Microchip Technology. It offers a balance of performance, memory, and cost, making it a popular choice for a wide range of embedded applications. With 128kB of flash memory, 4kB of Electrically

International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 46 No. 2 September 2024, pp. 527-536

Erasable Programmable Read-Only Memory (EEPROM), and 16kB of SRAM (Static Random-Access Memory), the ATmega1284 provides ample storage for both program code and data. Its Dual In-line Package (DIP) enables easy integration into various circuit designs. The ATmega1284's robust memory resources make it well-suited for tasks requiring significant data processing and storage, such as implementing complex algorithms, controlling multiple peripherals, and supporting advanced features like real-time operating systems.

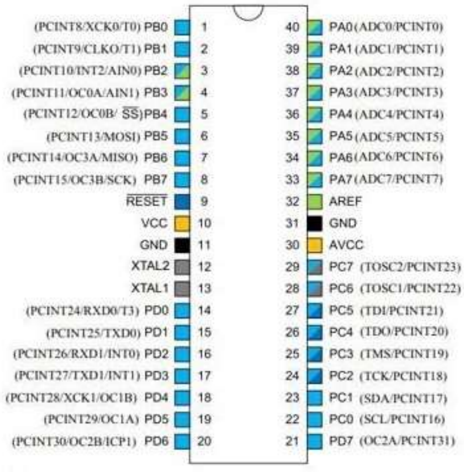


Fig.2 Pinout of ATmega1284

4. ACS712 Current Sensor

The ACS712 is a versatile current sensor based on the Hall Effect principle. It is designed to measure both Alternating Current (AC) and Direct Current (DC) by detecting the magnetic field generated around a conductor carrying electric current. The sensor's output is a linear voltage proportional to the measured current, providing a simple and efficient way to monitor current flow in various electronic circuits. The module typically includes a precision Analog-to-Digital Converter (ADC) that converts the analog output voltage into a digital value, which can be easily processed by a microcontroller such as an Arduino. By reading the digital value from the ADC, the microcontroller can calculate the corresponding current value and perform further calculations, such as power measurement.

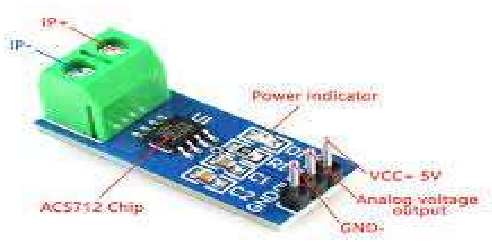


Fig.3 ACS712 Current Sensor Overview

International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/

Vol. 46 No. 2 September 2024, pp. 527-536

5. Micro SD (Secure Digital) Module

A Micro SD card reader module enables data transfer to and from Micro SD cards. It connects to a microcontroller (such as an Arduino) via an SPI (Serial Peripheral Interface) interface, typically using 6 pins (Chip Select (CS), Serial Clock (SCK), Master Out Slave In (MOSI), Master in Slave out (MISO), Voltage Common Collector (VCC) and GND) for communication. This module is essential for storing non-volatile data, like configurations, audio files, or images, in electronic projects.

Fig.4 MicroSD Module Schematic

6. IRF1404 Power MOSFET (Metal Oxide Semiconductor Field Effect Transistor)

The IRF1404 is a power MOSFET designed for high-power applications. It is a voltage-controlled device, meaning that the voltage applied to the gate controls the current flow between the drain and the source. The IRF1404 is typically used as a switch to control the flow of current in power circuits, or as an amplifier to control the voltage or current in a load.

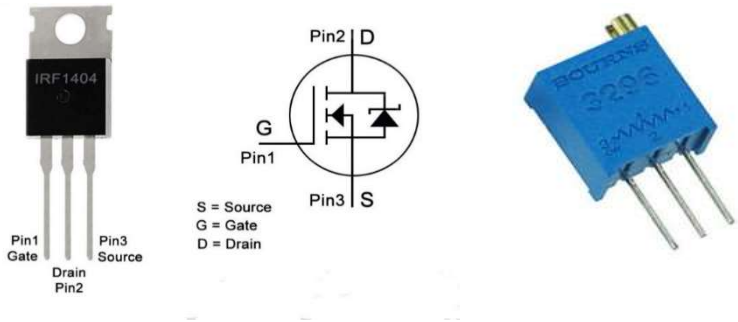


Fig.5 IRF1404 Power MOSFET Components

7. Shunt Resistor

A shunt is a precision low-value resistor designed to measure electrical current. It is connected in series with the circuit, and the voltage drop across the shunt is proportional to the current flowing through it. Shunts are typically made of materials with low temperature coefficients and high stability to ensure accurate measurements. Common applications of shunts include:

- Current measurement: Shunts are widely used in ammeters and power meters to measure DC and AC currents.
- Overcurrent protection: Shunts can be used in conjunction with circuit breakers or relays to protect circuits from excessive current.
- Battery monitoring: Shunts are used to measure the current flowing into or out of batteries, allowing for battery state-of-charge estimation.

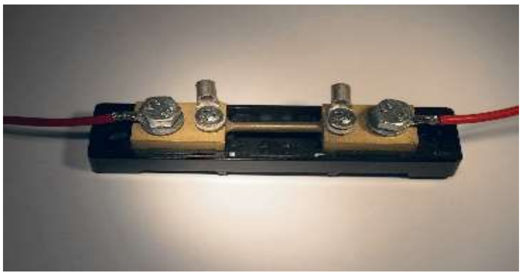


Fig. 6 Shunt Resistor

8. Organic Light-Emitting Diode (OLED) Display

An OLED consists of an organic film sandwiched between two electrodes. When a current is applied, the organic compound emits light. OLEDs offer several advantages over traditional Liquid Crystal Display (LCD), including higher brightness, better contrast, thinner and lighter form factors, lower power consumption, and potentially lower production costs.

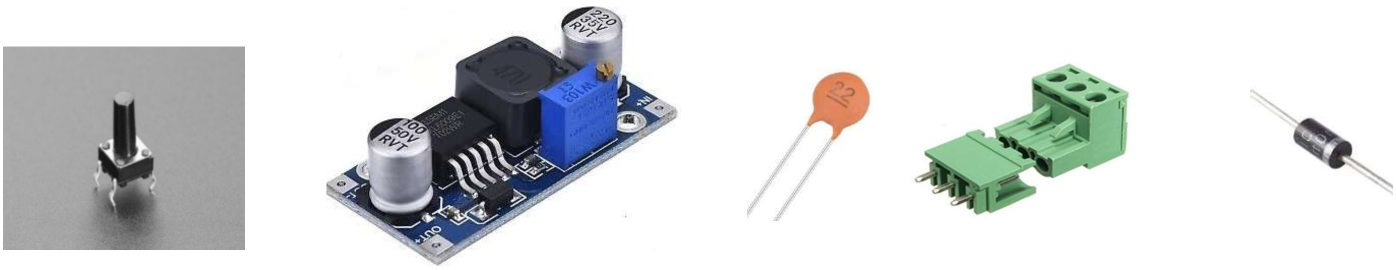
Fig. 6 OLED Display

9. Supplemental Circuit Parts

Figure 7 presents additional circuit components used in the project, complementing the previously mentioned elements.

International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 46 No. 2 September 2024, pp. 527-536



Push Button | Step-Down Module | Capacitor | Terminal Connector | Diode 1N4001

Fig.7 Additional Circuit Components

D. Data Acquisition and Processing

The device operates based on the battery voltage (5V or 12V). Once powered and connected to the battery, the process is initiated by inserting an SD card and pressing reset. The battery current, passing through a wound resistor, inducing a magnetic field, is measured by the ACS712 current sensor. The microcontroller digitizes the analog sensor output and calculates the current value. Real-time data is displayed on an OLED and simultaneously logged to an SD card. When the battery is depleted, as determined by a voltage threshold, the MOSFET interrupts the circuit.

III. RESULTS AND DISCUSSION

A. *Shunt Resistance Impact on Battery Performance*

The experiments conducted with different shunt resistances aimed to evaluate their impact on battery performance. By applying Ohm's Law, a stable direct current was maintained. The results, tabulated in Table I, provide valuable data on factors such as discharge time, current delivery, and the thermal effects associated with Joule heating.

Table I. Evaluation of Shunt Resistances on Battery Performance

Shunt Resistance (Ω)	Voltage (V)	Current (A)	Joule Heating (J)	Test Duration (h)	Capacity (Ah)
0.5	3.2	6.4	20.48	0.5	3.2
	3.7	7.4	27.38	0.43	3.2
	12	24	288	0.5	12
1	3.2	3.2	10.24	1	3.2
	3.7	3.7	13.69	0.86	3.2
	12	12	144	1	12
3	3.2	1.06	3.41	3	3.2
	3.7	1.23	4.56	2.59	3.2
	12	4	48	3	12

This table presents the results of tests conducted on three battery types using shunt resistors of varying values: 0.5Ω, 1Ω, and 3Ω. While the 0.5Ω shunt provides rapid results, it necessitates effective thermal management due to significant power dissipation. For a 12V system, this dissipation reaches 288J, potentially leading to excessive heat and posing a fire hazard, especially in a wooden

International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 46 No. 2 September 2024, pp. 527-536

enclosure. The shunt, weighing approximately 3g, can reach temperatures of up to 249°C. This shunt is particularly suitable for testing 3.2V lithium batteries, utilizing both PWM (Pulse Width Modulation) and PID (Proportional, Integral and Derivative) control strategies.

B. *Microcontroller-Based Capacitance Meter*

A 3Ω shunt resistor, an ACS712 current sensor, and an ATmega1284 microcontroller were used to build a battery monitoring system. A PID controller (proportional (Kp = 35), integral (Ki = 15), and derivative (Kd = 0.05) gains) with an IRF1404 PMOS, P-type Metal-Oxide-Semiconductor, transistor maintained a constant 2A load on a 3.2V, 3.2Ah battery until the voltage reached 2.4V. To track battery performance, an SD card was used to log data to a "datalog.txt" file. This file recorded time, voltage, current, and estimated capacity at a 1Hz sampling rate.

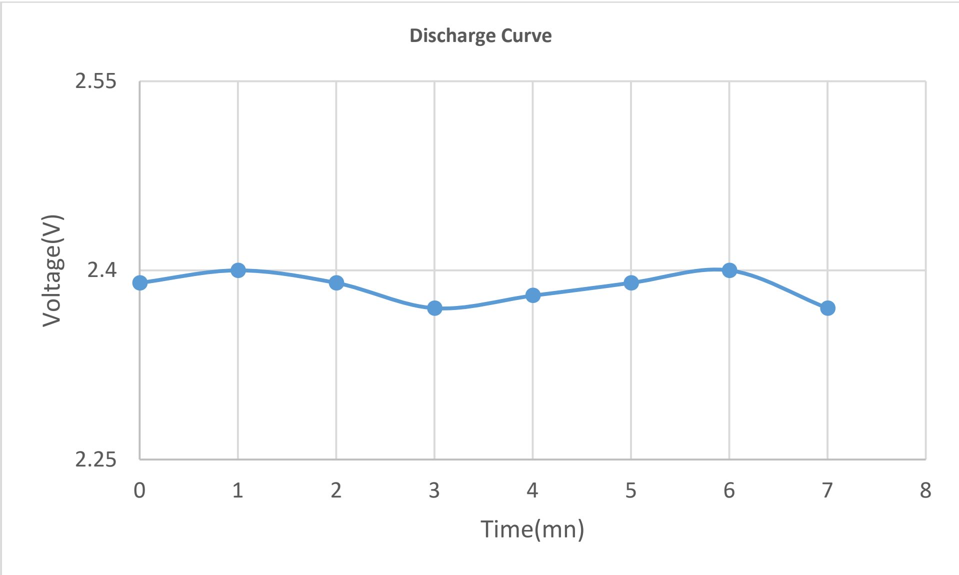


Fig. 8 Discharge Curve of a 3.5V Lithium Battery

Figure 8 illustrates the experimentally measured discharge curve for a 3.5V lithium battery. The voltage variations over time are clearly visible. The voltage gradually decreases, indicating the reduction of available charge in the battery as time progresses. This curve provides a visual representation of the discharge duration, allowing for a comparison between the actual performance of the battery and its specified characteristics.

International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 46 No. 2 September 2024, pp. 527-536

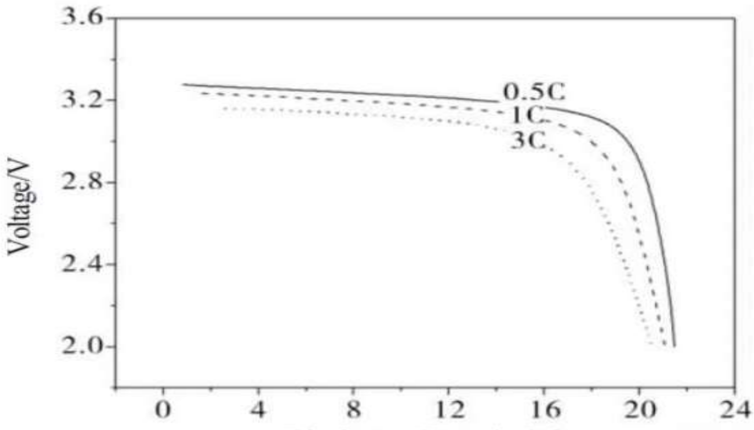


Fig. 9: Theoretical Discharge Curve for a 3.5V Lithium Battery

Figure 9 shows a theoretical discharge curve for a 3.5V lithium battery. It is used as a reference to compare the experimental data (Fig. 8) with the theoretical predictions. By comparing the two figures, we can check if the behavior observed during the experiment aligns with the theoretical expectations or if any deviations are caused by external factors or material limitations.

Comparing the theoretical and experimental discharge curves (Fig.8 and Fig. 9), we observe a strong correlation in battery behavior. Both profiles exhibit a similar discharge duration of approximately 7-8 minutes, with relatively flat voltage plateaus. While the experimental curve shows slightly steeper slopes and minor fluctuations, particularly towards the end of discharge, the overall agreement between the two curves suggests that the theoretical model accurately predicts the battery's performance under these conditions. The observed discrepancies are within expected margins, given the inherent limitations of theoretical models in capturing all real-world factors.

These two figures, 8 and 9, are complementary, as they allow for the analysis and verification of the actual performance of the battery in comparison to a theoretical model, thereby providing valuable insights for evaluating the capacity and lifespan of batteries in various usage scenarios.

C. Discussion

The battery's discharge curve analysis, based on 7 minutes of voltage data, reveals exceptional stability. A calculated slope of -0.625 mV/min using the least squares method indicates an extraordinarily slow voltage decline. This surpasses initial expectations, suggesting a high-quality battery or advanced battery management.

Such consistent performance throughout discharge is ideal for applications demanding a steady voltage supply. The observed behavior aligns with advanced battery technologies like $LiFePO_4$. The minimal voltage drop confirms both the battery's quality and the Arduino-based capacimeter's precision in detecting subtle voltage variations.

This exceptional stability can lead to improved energy efficiency and predictability. The device's ability to accurately measure this stable performance makes it a valuable tool for battery quality assessment, especially in identifying high-performance batteries that maintain consistent output. This level of stability and the capacimeter's precision provide valuable insights for battery selection and application in fields requiring reliable power.

Battery discharge time varies based on the shunt resistor, current sensor, and voltage sensor. Our setup (3 Ω, ACS712 and MOSFET 1404) requires careful selection of the shunt resistor to avoid excessive discharge and battery damage.

The increase in power due to the Joule effect impacts energy efficiency, heat dissipation, component lifespan, and system monitoring, especially in a portable capacitance meter. More power results in greater energy losses as heat, reducing system efficiency. It is crucial to select low-resistance components and minimize high currents to achieve accurate measurements. The heat generated accelerates component degradation, making heat-resistant materials necessary to extend their lifespan and ensure the proper functioning of the capacitance meter.

IV. CONCLUSION

Our study has demonstrated the effectiveness of an Arduino-based battery capacity measurement tool, offering an affordable and accurate solution for evaluating lithium battery performance. The results obtained, characterized by a stable discharge curve with a slope of -0.625 mV/min, attest to the reliability and precision of our device.

The use of different shunt resistances allowed for optimization of system performance. Notably, the use of a 3Ω resistance proved particularly effective for 3.2V batteries, offering a good balance between accuracy and thermal management. The integration of a PID controller with an IRF1404 PMOS transistor maintained a constant 2A load, ensuring consistent measurements.

Our approach, combining an ATmega1284 microcontroller, an ACS712 current sensor, and an SD card logging system, offers a comprehensive solution for monitoring battery performance. This method not only allows for verification of actual battery capacity but also enables analysis of battery behavior over time.

For the future, we envision enhancing our device by incorporating wireless communication features to facilitate remote data collection and analysis for photovoltaic solar power plants. Additionally, adapting the system to test a wider range of battery types and capacities could expand its application in various industrial and research fields.

In conclusion, our tool addresses the growing need for an accessible and reliable solution for battery performance verification, thus contributing to better energy management and consumer protection.

REFERENCES

[1] Ahmadi, P., & Torabi, F. (2020). *Simulation of battery systems: Fundamentals and applications*. Academic Press.

[2] Aloisio, D., Campobello, G., Leonardi, S. G., Sergi, F., Brunaccini, G., Ferraro, M., Antonucci, V., Segreto, A., & Donato, N. (2020). A machine learning approach for evaluation of battery state of health. In *24th IMEKO TC4 International Symposium 22nd International Workshop on ADC and DAC Modelling and Testing IMEKO TC-4 2020* (pp. 14-16). Palermo, Italy.

[3] Australian Academy of Sciences. (n.d.). How a battery works. https://www.science.org.au/curious/technology-future/batteries

[4] Australian Academy of Sciences. (n.d.). Lithium-ion batteries. https://www.science.org.au/curious/technology-future/lithium-ion-batteries

[5] Drouet, H. (n.d.). Comment choisir une batterie : marques, génériques et contrefaçons [How to choose a battery] [Blog post]. https://www.luzphotos.com/herve-drouet-photographe

[6] Figgener, J. (2023, December 14). The financial implications of inaccurate SOC in LFP batteries. [Blog post]. https://www.accure.net/battery-knowledge/lfp-soc-estimation-challenges.

[7] Hosen, M. S., Jaguemont, J., Van Mierlo, J., & Berecibar, M. (n.d.). Battery lifetime prediction and performance assessment of different modeling approaches. *iScience*.

[8] Maltezo, M. R. C., Thio-ac, A. C., Castillo, A. M. C., Gattu, L. E., Hernandez, C. E. A., Labuan, J. J. C., Navales, L. F., Sopeña, E. C., Arago, N. M., Galido, E. A., Madrigal, G. A. M., Pascion, C. G., & Tolentino, L. K. S. (2021). Arduino-based battery monitoring system with state of charge and remaining useful time estimation. International Journal of Advanced Technology and Engineering Exploration, 8(76). https://ssrn.com/abstract=3828898

[9] Pascoe, P. E., & Anbuky, A. H. (2003). Automated battery test system. *Measurement, 34*(4), 325-345.

[10] Roman, D., Saxena, S., Robu, V., et al. (2021). Machine learning pipeline for battery state-of-health estimation. *Nature Machine Intelligence, 3*, 447–456.

International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 46 No. 2 September 2024, pp. 527-536

[11] Scrosati, B., & Garche, J. (2010). Lithium batteries: Status, prospects and future. *Journal of Power Sources, 195*(9), 2419-2430.

[12] Wickramaarachchi, K., & Minakshi, M. (2022). Status on electrodeposited manganese dioxide and biowaste carbon for hybrid capacitors: The case of high-quality oxide composites, mechanisms, and prospects. *Journal of Energy Storage, 56*(C), 106099.

[13] Zheng, L., et al. (2020). X- tomography for battery degradation analysis. *Analytical Chemistry, 92*(15), 10123-10131.