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Battery Monitoring System with Internal Impedance Reading (BMS-IIR) Using IoT

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Abstract: The purpose of this research is to develop a battery management system capable of directly reading internal impedance. Currently, many systems used in major markets are based on lead acid batteries (LABs) because of their effectiveness in powering such major applications as telecommunication systems, rectifiers, uninterruptable power supplies (UPSs), forklifts, and buggy systems. LABs are easily available at a low cost. But they last only two to five years because of factors that erode performance: depth of discharge (DOD), the lack of any mechanism to prevent excessive charging, extreme temperatures, and the charging algorithm. The popular lithium iron phosphate (LiFeP04) battery has a longer life cycle, higher energy density, and a longer shelf life, and it can provide continuous power over longer periods of time. But because it is expensive, in many contexts it is inadvisable to replace LABs with LiFeP04 batteries. As an alternative, this paper introduces a battery monitoring system with internal impedance reading (BMS-IIR). A BMS-IIR is an electronic monitoring system equipped with a voltage sensor and a Wi-Fi module. It uses Arduino Uno scripting to ensure real-time monitoring of the voltage of every battery and to ensure that impedance readings are in a condition of equal and balanced charge. The experimental results indicate that data on the voltage and impedance of all four batteries in BMS-IIR devices are accurately read and monitored in real time using the BMS-IIR cloud storage setup.

Keywords: battery management system, internal impedance reading, lead acid batteries, lithium iron phosphate, lifespan, Internet of Things.

使用物联网的具有内部阻抗读数(BMS-IIR)的电池监控系统

摘要：本研究的目的是开发一种能够直接读取内部阻抗的电池管理系统。目前，主要市场中使用的许多系统都基于铅酸电池(实验室)，因为它们可以有效地为电信系统、整流器、不间断电源(UPS)、叉车和越野车系统等主要应用供电。实验室很容易以低成本获得。但由于影响性能的因素，它们只能持续两到五年：放电深度(国防部)、缺乏任何防止过度充电的机制、极端温度和充电算法。流行的磷酸铁锂（磷酸铁锂）电池具有更长的生命周期、更高的能量密度和更长的保质期，并且可以提供更长时间的持续电力。但由于价格昂贵，在许多情况下不建议用磷酸铁锂04电池代替实验室。作为替代方案，本文介绍了具有内部阻抗读数的电池监控系统(BMS-IIR)。BMS-IIR是配备电压传感器和无线上网模块的电子监控系统。它使用阿杜诺脚本来确保实时监控每个电池的电压，并确保阻抗读数处于均衡充电的状态。实验结果表明，使用BMS-IIR云存储设置可以准确读取和实时监控BMS-IIR设备中所有四个电池的电压和阻抗数据。

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关键词：电池管理系统、内部阻抗读数、铅酸电池、磷酸铁锂、寿命，物联网。

1. Introduction

Most industries, including manufacturing, medical, agriculture, transportation, telecommunication, and education industries, employ electrical components that require major consumption of electrical energy. Using batteries is crucial to ensure that backup mechanisms are in place if and when the main power source fails. The major types of backup battery include lead acid batteries (LABs) and lithium-ion batteries (LIBs). Fig. 1 illustrates the significant differences between LABs and LIBs.

	Lead Acid Batteries	Lithium-Ion Batteries (LiFePO4)
Power Density	40 watts per kilogram	125 watts per kilogram
Cycle Life	200 @ 100% DoD	2800 @ 100%DoD
Usable Energy	50%	80%
Temperature sensitivity	Degrades significantly above 76°F (25°C)	Degrades above 95°F (45°C)
Voltage Per Cell	2 V	3.2 V
Maintenance Requirements	Regular maintenance, every 3 months	Basic annual maintenance

Fig. 1 Differences between LAB and LIB [1]

Despite the importance of reliable battery management, there has been too little investigation into how to enhance that management to ensure that batteries are used as efficiently as possible. Another concern is the possibility that a damaged LAB or LIB will have a negative effect on the environment when it is recycled. The problem of an unbalanced battery becomes serious only after a sufficiently high number of charge-and-discharge cycles. The lifespan of a battery depends in part on how well it is treated as it is discharged and recharged. An intelligent battery management system reduces the cost and energy required to maintain physical equipment.

A battery management system (BMS) is an electronic system that manages the physical conditions of the battery, including current, voltage, and temperature, in order to prevent unsafe operation. Parameters that a BMS must take into account include voltage; temperature; state of charge (SOC) or depth of discharge (DOD), indicating the charging level; state of health (SOH), indicating the remaining percentage of the battery's original capacity; state of power (SOP), indicating the total available power during a specified usage interval given the temperature and other conditions; state of safety (SOS); and coolness of battery flow.

In a battery pack, monitoring of batteries is crucial. Reading the internal impedance of a battery determines the SOH of each lead acid battery. Our BMS-IIR can monitor SOC, DOD, and SOH; balance the batteries; protect them from overcharging to prevent overheating; and provide accurate real-time measurements.

2. Related Works

Our review of the literature focuses on LAB management. According to [2], LABs had to deal with such problems as how to predict battery power, lengthen short battery lifetimes, and balance battery packs. Most important was the need to monitor battery states accurately in real time while consuming only a low amount of power. A battery monitoring system (BMOS) [3] was proposed to monitor rechargeable battery cells using three parameters: battery voltage, current, and SOC. The system was connected using the Arduino Uno microcontroller, a liquid crystal display (LCD), and sensors. The results showed that battery voltage was still 11.1V when SOC was 100%, and the SOC declined to linear as voltage decreased to 3.9V at an SOC of 0%.

Automatic analysis and monitoring of battery health was proposed in order to provide indications of LAB level, SOC, voltage, current, and the balance of charges of a battery in real situations [4]. Using Wi-Fi as the means of network communication, the battery information from each client location is further analyzed. The functionality of the battery is consistently monitored for sudden charges and discharges of the voltage in battery banks, and battery conditions are viewed in the cloud with the help of an Internet of Things (IoT) module. When the battery level reaches a certain low state, a charging circuit is triggered and information is sent to the person using the IoT module.

The purpose of a BMS [5] is to identify the emission of gases from the battery in order to determine whether it has been overcharged as well as to monitor variables like voltage and current. Most important is monitoring the temperature using a safety temperature monitor (STM) controller and using sensors equipped with a GPS module to enable vehicle tracking. Data are stored in the cloud. A high temperature indicates that the battery is unstable or is being subjected to abnormal conditions. To measure temperature, the researchers used a thermistor that can show changes of resistance when temperature changes. They found that when a thermistor with a negative temperature coefficient is used, it exhibits 10K ohms of resistance in room temperature.

A short and concise battery model is a must for a battery management system (BMS) [6] due to the increasing number of electrical equipment in the latest vehicles. Using their BMS, they discovered that for each type of battery, a special-purpose battery management optimization should be put to encounter the behavior and the characteristic qualities that could vary between different types. A test case with different variable setups for different methods to measure the different characteristic curves has been presented.

A Battery Charging and Cell Balancing (BCCB) [7] is proposed using two cells battery of 12V 7.2 Ah LAB. The device is connected in series to monitor the voltage and current for good operating conditions. Battery model equations are provided to serve as SoC observers in predicting and correcting the current charges of each cell. A dissipative equalization of voltage and current formula is proposed for cell equalization among the connected cells. The schematic circuit is derived, and simulation is done with Proteus and NI Multisim. Results show that a charging strategy in cell equalization allows an additional 31% voltage energy to be stored in the battery pack as compared to the previous strategy, which stops charging when the strongest cell in the battery pack reaches the maximum voltage allowable. The study has improved significantly in battery charging and cell balancing.

[8] analyze their proposed battery management system to cater to electric vehicles and large-scale stationary energy storage. The analysis caters to issues such as testing and functionalities, design topology and architecture, and BMS safety aspects and reviews current related standards and codes of BMS. They provide a framework for developing a new standard, especially on the safety and operational risk. The four main areas focused on are construction, operational parameters, data integration, and installation for improvement of BMS safety and performance, which complies with the basic standards of, for example, CSA, IEEE, UL, NEC, and IEC. This is to ensure safety requirements are validated and adhered to.

In [9], the Gen. 2 is commenced based on the internet of things (IoT) for data monitoring on a remote basis from a few geographical apart installation sites. The Gen. 2 underlies continuous remote monitoring by using cloud servers and can support single-cell measurements and enhance communication reliability.

Research based on cloud infrastructure has commenced many efforts [10]–[12] to enable real-time monitoring, especially on big data [13].

3. Research Methodology

The BMS-IIR research methodology consists of 4 phases. Phase 1 is the sensor component setup. This phase begins with the assembling of the small component of the ESP8266 module, voltage sensor, and buck converter. Then, it is followed by Phase 2, where the components are connected to the laptop/desktop, and the programming code is written to establish the connection among the components. Next, Phase 3 is the database being set up to store the data sent from sensor to database through a cloud server. Phase 4 is the BMS-IIR app's development to retrieve the data from the cloud database and is viewed through mobile devices. Thus, users can view the BMS-IIR real-time data through the BMS-IIR web system and BMS-IIR apps. Refer to Fig. 2 for the BMS-IIR research methodology.

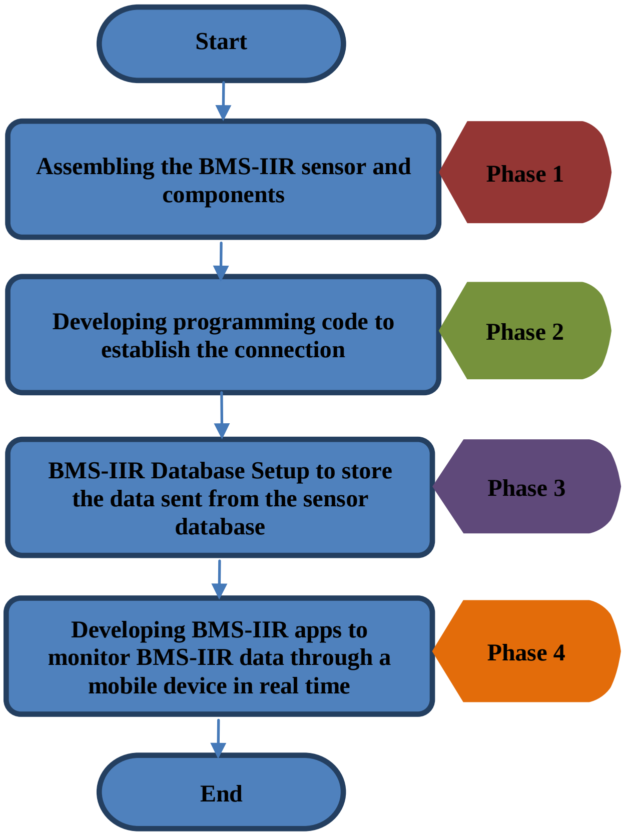

Fig. 2 BMS-IIR research methodology

4. Fundamentals of Battery Calculation

For simple calculation of battery voltage and impedance, consider the following terms [14]. Let R = {R | resistance}, X_L= {X_L | Inductive reactance}, X_C = {X_C | Capacitive reactance}, then

$$Voltage, \Delta V = \{\Delta V \mid changes\ in\ voltage\} \tag{1}$$

$$Impedance, Z = R\ or\ XL\ or\ XC\ (if\ only\ one\ is\ present) \tag{2}$$

$$Impedance, Z = \sqrt{}(R2 + XL2)\ or\ \sqrt{}(R2 + XC2)\ (if\ both\ R\ and\ XL\ or\ XC\ are\ present) \tag{3}$$

5. Project Brief

The BMS-IIR is based upon online monitoring of LAB via the IoT. The voltage sensor is the IoT component coded using Arduino Uno to connect with cloud database. For this BMS-IIR project, the focus of monitoring goes on the voltage and impedance readings as the primary parameters for battery conditions. It is proposed to solve three main issues. First, it is reported that almost 80% of uninterruptable power supply (UPS) failures are due to undetected battery failure. Second, most manufacturers and factories spend a lot of time and money in solving maintenance issues involving the lead-acid and lithium-ion batteries. Third, during every failure, it is difficult to detect which battery was affected, when the failure happened, and what caused the failure. The main objectives of our BMS are to monitor battery status in terms of voltage and impedance in real time, and to reduce manpower efforts in manual monitoring. The wireless network is used as the backbone network. The information collected from all the associated battery clients in the system is analyzed in an asynchronous transmission control protocol/user datagram protocol based on a cloud server. Refer to Fig. 3 for the BMS-IIR architecture diagram.

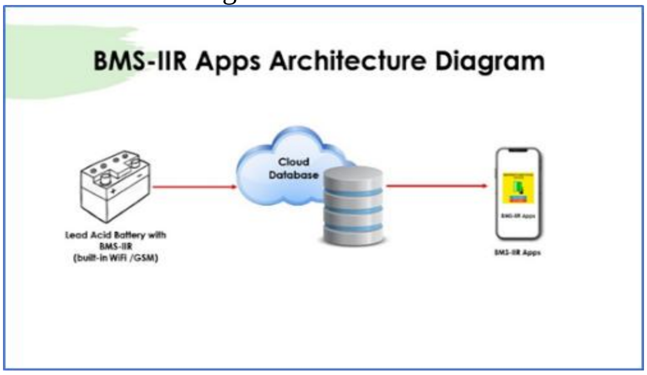

Fig. 3 BMS-IIR architecture

6. Design of BMS-IIR

The BMS-IIR device comprises three main hardware components as shown in Table 1. The components are one Wi-Fi module, NodeMCU (ESP8266), one voltage sensor, and one buck converter. To enable real-time monitoring of the voltage and impedance dataset, the BMS-IIR system is developed using only a few software components, as stated in Table 2.

Table 1 BMS-IIR hardware specification

Hardware	Function and specification
NodeMCU (ESP8266) module 	As a microcontroller, it gathers sensor data and provides connectivity to the gateway for transmitting data. It has a micro-USB for flashing or reprogramming via Arduino IDE and can be operated from a voltage as low as 3.3V. The module also included 3.3V and 5V power regulators to stabilize output voltage and provide more flexibility regarding the type of sensor to be used.
Voltage sensor 	Voltage sensors monitor a battery pack used to power an Arduino that is attached with two resistors wired as a voltage divider
Buck converter 3.3V	Supplying power to low voltage circuits from a single Li-Ion cell battery or USB power. It provides up to 600-mA load current across the entire input voltage range of 3.5 to 5.5V.

Table 2 BMS-IIR software specification

Microsoft Windows 8 and above	Operating system (OS)
Google Chrome, Internet Explorer and Mozilla Firefox	Web browser
Arduino IDE 1.8.9	Coding for the device platform
Dart 2.13.1	Page scripting
Apache Tomcat	Web server
MySQL	Database Management System
Flutter 2.2.1	Framework

The BMS-IIR project is based on Arduino Uno to monitor and control the sensor battery. These sensors are used to measure the temperature and voltage of the lead-acid battery and send the values to the Arduino Uno for processing. Based on the instructions given, the data will then be displayed on the database. The processes occur when the battery supplies voltage and temperature to the voltage sensor. The block diagram of BMS-IIR is shown in Fig. 4.

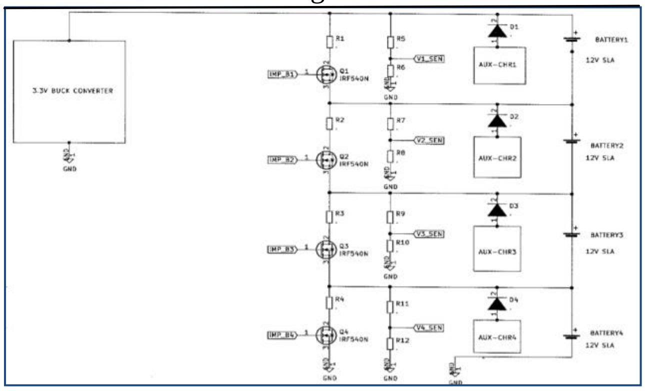

Fig. 4 BMS-IIR schematic diagram for testing and running the pilot project in real field trial/site

Four 12V batteries are applied for our BMS-IIR device. Apart from this, there are two readings of voltage and impedance. Thus, in our BMS-IIR, there are a total of eight readings, with four readings of voltage and the remaining four readings of the impedance of each battery. Our BMS-IIR would display two parameters: voltage (in Volt, V) and impedance (in ohms, Ω). Table 3 represents a detailed explanation of the seven parameters in BMS-IIR.

Table 3 BMS-IIR parameter description

Parameter	Description
Voltage	The pressure or force that pushes the current inside a conductor is the same as the force experienced by the negative charge (in Volt, V)
Impedance	The measure of the overall opposition of a circuit to current, i.e., how much the circuit impedes the flow of charge (in Ohms, Ω)

The sample of calculation is given in Fig. 5.

```
// Voltage Probe - Max input is 25 v
// Uses 3.3 k and 15 k resistors in series
// The factor is (R1+R2)/R2
// Example R1 = 15k, R2 = 3.3 k,
// Factor is 18.3/3.3 = 5.54

Double Vout; // Voltage at pin A0
Double Vin; // Voltage being measured, max = 25 v
Double factor = 4.54;
Double Vcc = 5.00; // This is the Arduino's Vcc and
adjustable
```

Fig. 5 Sample of calculation of factors with two resistors

7. Result and Discussion

7.1. Database Design

The design of the BMS database is referred to in Fig. 6. The name of the BMS-IIR database is *db_bms2*. There are four batteries in one BMS-IIR system with two parameter readings of voltage and impedance. Thus, there are eight readings of four voltage readings and four impedance readings.

A parent table is named *tbl_device* and connected to a child table identified as *tbl_device_manager*.

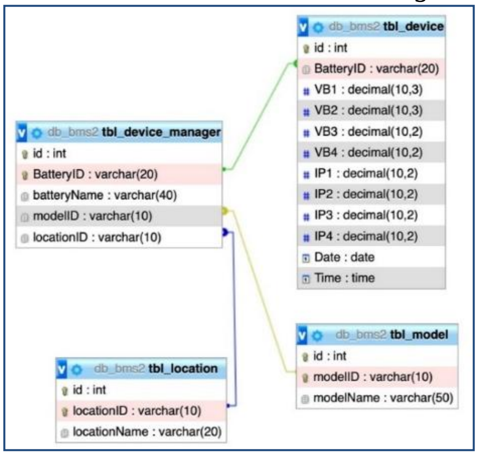

Fig. 6 BMS-IIR database design

7.2. Real-Time Database Experimentation

The *tbl_device_manager* table is then linked with another two child tables, *tbl_location* and *tbl_model*. For each table involved, the data type for every field is illustrated in Fig. 7.

BMS-IIR system can be accessed at https://my-developments.com/phpmyadmin. Fig. 6 illustrates the schema in db_bms2.

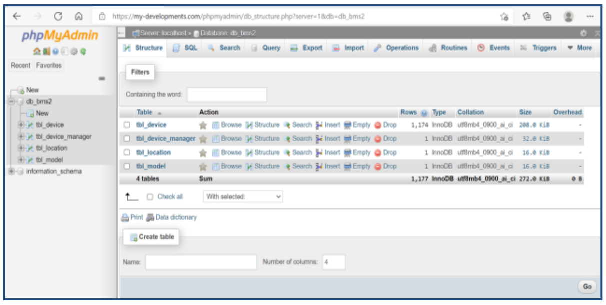
Fig. 7 BMS-IIR scheme of db_bms2

Fig. 8 depicts the real-time data from the BMS-IIR cloud database retrieved from table *tbl_device*.

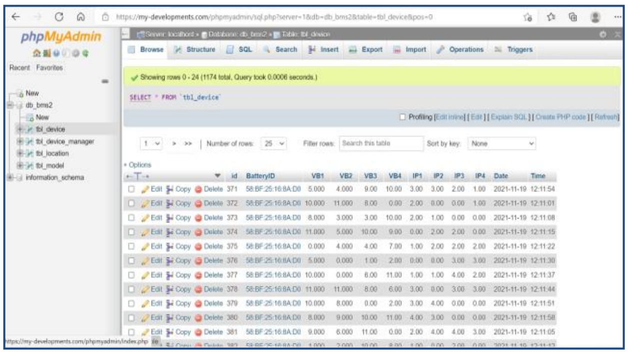
Fig. 8 BMS-IIR table on tbl_device

7.3. Real BMS-IIR Implementation

The real development of the BMS-IIR device is assembling the hardware components, as shown in Table 1. Fig. 9 and 10 show the actual view of the project.


Fig. 9 BMS-IIR device

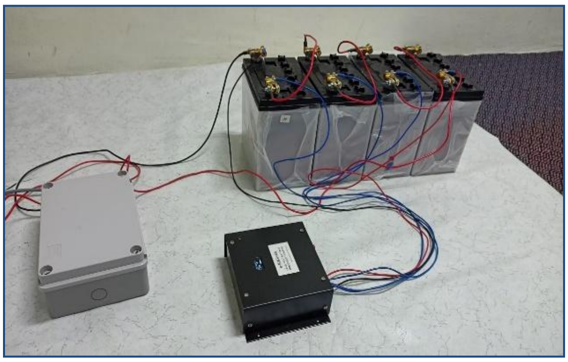
Fig. 10 Top view of the BMS-IIR system consists of a BMS-IIR device and a 3.3V buck converter

7.4. Proposed Interface

The draft interface for the BMS-IIR system consists of only three interfaces with one main interface and two sub interfaces. The sub-interfaces will display the list of 4 batteries attached and the voltage and impedance readings for each identified battery. The initial sketch diagrams are shown in Fig. 11-13.

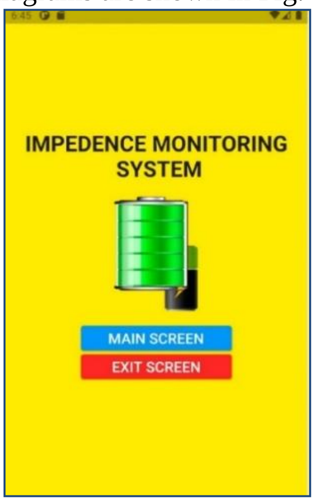

Fig. 11 Main menu of BMS-IIR after clicking the icon

Fig. 12 Main menu of BMS-IIR after clicking the icon

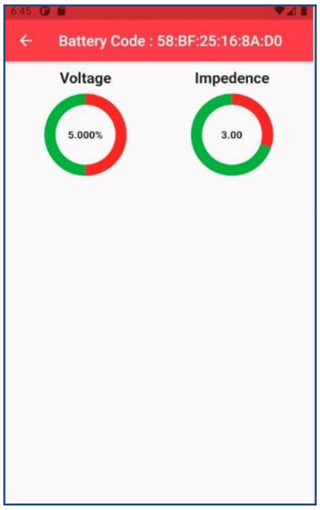

Fig. 13 Main menu of BMS-IIR after clicking the icon

8. Conclusions

The BMS-IIR system that has been developed is considered successful because it has achieved the study's main purpose with the ability to reveal the real-time status of each battery device from the data read in the BMS-IIR cloud database. When real-time data can be read, the voltage sensor in the BMS-IIR device is functioning properly and correctly, thus being an indicator of a successfully connected cloud database schema. This project only covers the voltage and impedance levels since both readings reflect the internal resistance readings. The internal resistance helps to identify problems with inter-cell connections, corrosion of terminals, and loose connection hardware. With real-time monitoring, voltage and impedance results are streamed at each set of intervals. Therefore, any anomalies or abnormal conditions can be detected at an early stage [15].

Moreover, implementing IoT in the BMS-IIR project can speed up the real-time detection process, and battery state analysis can be well visualized [16-18]. Our strength refers to the battery monitoring and maintenance since no manual checks are required to indicate our BMS-IIR is reliable [19]. Thus, the battery maintenance cost reduces with the auto-monitoring and reviewing the real-time battery status. The limitation would refer to the reliability of battery data sent and received. Our next paper will discuss the programming flow and share the detailed code for this BMS-IIR app.

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References

[1] KESHAN H., THORNBURG J., and USTUN T. S. Comparison of lead-acid and lithium ion batteries for stationary storage in off-grid energy systems. Proceedings of the 4th IET Clean Energy and Technology Conference, Kuala Lumpur, 2016, pp. 1-7. https://doi.org/10.1049/cp.2016.1287

[2] WANG P., & CHANGQING Z. Summary of Lead-Acid Battery Management System. *IOP Conference Series: Earth and Environmental Science*, 2020, 440(2): 022014. https://doi.org/10.1088/1755-1315%2F440%2F2%2F022014

[3] FITRIYAH R. N., & MUDA W. M. W. Development of Battery Monitoring System Using Arduino Uno Microcontroller. *Universiti Malaysia Terengganu Journal of Undergraduate Research*, 2020, 2(4): 41-50. https://doi.org/10.46754/umtjur.v2i4.179

[4] POONAM P., GUPTA R., TIWARI S., and SHARMA A. IoT based air pollution monitoring system using Arduino. *International Research Journal of Engineering and Technology*, 2017, 4(10): 1137-1140.

[5] SIVARAMAN P., & SHARMEELA C. IoT-Based Battery Management System for Hybrid Electric Vehicle. In: CHITRA A., SANJEEVIKUMAR P., HOLM-NIELSEN J. B., and HIMAVATHI S. (eds.) *Artificial Intelligent Techniques for Electric and Hybrid Electric Vehicles*. Scrivener Publishing LLC, Beverly, Massachusetts, 2020: 1-16. https://doi.org/10.1002/9781119682035.ch1

[6] PHILIP D., & SOURKOUNIS C. Generalized Lead-Acid based Battery Model used for a Battery Management System. *Athens Journal of Technology & Engineering*, 2016, 3(3): 255-270. https://doi.org/10.30958/AJTE.3-3-4

[7] NAMITH T., & SHANKPAL P. Design and development of efficient battery charging and cell balancing for battery management system. *SASTech - Technical Journal of RUAS*, 2012, 11(2): 15-22. https://indianjournals.com/ijor.aspx?target=ijor:sastech&volume=11&issue=2&article=003

[8] HOSSAM A. G., OTHMAN A. M. and ABDUSSAMI

M. R. Review of Battery Management Systems (BMS) Development and Industrial Standards. *Technologies*, 2021, 9(2): 28. https://doi.org/10.3390/technologies9020028

[9] MUKAITANI I., MIYAMOTO A. K. Y., and KAMIJO K. H. T. *Next Generation Wireless Battery Monitoring System (Gen. 2)*, 2018. https://www.mc.showadenko.com/english/report/060/60_tr02.pdf

[10] BAKAR W. A. B. W. A., ABDULLAH Z. B., SAMAN M. Y. B. M., MAN M. B., HERAWAN T., and HAMDAN A. R. Incremental-Eclat Model: An Implementation via Benchmark Case Study. In: SOH P., WOO W., SULAIMAN H., OTHMAN M., and SAAT M. (eds.) *Advances in Machine Learning and Signal Processing. Lecture Notes in Electrical Engineering*, Vol. 387. Springer, Cham, 2016: 35-46. https://doi.org/10.1007/978-3-319-32213-1_4

[11] BAKAR W. A. W. A., MAN M., MAN M., and ABDULLAH Z. I-Eclat: Performance enhancement of Eclat via incremental approach in frequent itemset mining. *TELKOMNIKA (Telecommunication, Computing, Electronics and Control)*, 2020, 18(1): 562-570. https://doi.org/10.12928/telkomnika.v18i1.13497

[12] SABRI I. A. A., & MAN M. Improving performance of DOM in semi-structured data extraction using WEIDJ model. *Indonesian Journal of Electrical Engineering and Computer Science*, 2018, 9(3): 752-763. https://doi.org/10.11591/IJEECS.V9.I3.PP752-763

[13] BAKAR W. A. W. A., JALIL M. A., MAN M., ABDULLAH Z., and MOHD F. Postdiffset: an Eclat-like algorithm for frequent itemset mining. *International Journal of Engineering & Technology*, 2018, 7(2.28): 197-199. https://doi.org/10.14419/ijet.v7i2.28.12911

[14] RUFF B. *How to Calculate Impedance.* wikiHow, 2022. https://www.wikihow.com/Calculate-Impedance

[15] JUSOH J. A., & MAN M. Modifying iEclat Algorithm for Infrequent Patterns Mining. *Advanced Science Letters*, 2018, 24(3): 1876-1880. https://doi.org/10.1166/ASL.2018.11180

[16] YUSOF M. K., & MAN M. Efficiency of JSON for data retrieval in big data. *Indonesian Journal of Electrical Engineering and Computer Science*, 2017, 7(1): 250-262. https://doi.org/10.11591/IJEECS.V7.I1.PP250-262

[17] YUSOF M. K., & MAN M. Efficiency of JSON approach for data extraction and query retrieval. *The Indonesian Journal of Electrical Engineering and Computer Science*, 2016, 4(1): 203-214. http://doi.org/10.11591/ijeecs.v4.i1.pp203-214

[18] AL-AMRI R., MURUGESAN R. K., MAN M., ABDULATEEF A. F., AL-SHARAFI M. A., and ALKAHTANI A. A. A Review of Machine Learning and Deep Learning Techniques for Anomaly Detection in IoT Data. *Applied Sciences*, 2021, 11(12): 5320. https://doi.org/10.3390/app11125320

[19] ALQATAN S., NOOR N. M. M., MAN M., and MOHEMAD R. An empirical study on success factors to enhance customer trust for mobile commerce in small and medium-sized tourism enterprises (SMTES) in Jordan. *Journal of Theoretical and Applied Information Technology*, 2016, 83(3): 373-398. http://www.jatit.org/volumes/Vol83No3/8Vol83No3.pdf

参考文:

[1] KESHAN H.、THORNBURG J. 和 USTUN T. S. 用于离网能源系统中固定存储的铅酸和锂离子电池的比较。第四届IET清洁能源与技术会议论文集，吉隆坡，2016年，第1-7页。https://doi.org/10.1049/cp.2016.1287

[2] WANG P., & CHANGQING Z. 铅酸蓄电池管理系统综述。眼压会议系列：地球与环境科学，2020，440(2)：022014. https://doi.org/10.1088/1755-1315%2f440%2f2%2f022014

[3] FITRIYAH R. N. 和 MUDA W. M. W. 使用阿杜诺微控制器开发电池监控系统。马来西亚登嘉楼大学本科生研究杂志，2020，2(4)：41-50. https://doi.org/10.46754/umtjur.v2i4.179

[4] POONAM P.、GUPTA R.、TIWARI S. 和 SHARMA A.
使用阿杜诺的基于物联网的空气污染监测系统。国际工程技术研究杂志, 2017, 4(10): 1137-1140.

[5] SIVARAMAN P., 和 SHARMEELA C. 基于物联网的混合动力电动汽车电池管理系统。在：CHITRA A.、SANJEEVIKUMAR P.、HOLM-NIELSEN J. B. 和 HIMAVATHI S.（编辑）电动和混合动力电动汽车的人工智能技术。书记员出版有限责任公司，马萨诸塞州贝弗利，2020：1-16。https://doi.org/10.1002/9781119682035.ch1

[6] PHILIP D., & SOURKOUNIS C. 用于电池管理系统的基于铅酸的广义电池模型。雅典技术与工程杂志，2016年，3(3)：255-270。https://doi.org/10.30958/AJTE.3-3-4

[7] NAMITH T., & SHANKPAL P. 用于电池管理系统的高效电池充电和电池平衡的设计和开发。SASTech-街道技术期刊，2012，11 (2)：15-22。https://indianjournals.com/ijor.aspx?target=ijor:sastech&volume=11&issue=2&article=003

[8] HOSSAM A. G.、OTHMAN A. M., 和 ABDUSSAMI M. R. 电池管理系统(BMS)开发和工业标准审查。技术, 2021, 9(2): 28. https://doi.org/10.3390/technologies9020028

[9] MUKAITANI I.、MIYAMOTO A. K. Y. 和 KAMIJO K. H. T. 下一代无线电池监控系统（第2代），2018年。https://www.mc.showadenko.com/english/report/060/60_tr02.pdf

[10] BAKAR W. A. B. W. A.、ABDULLAH Z. B.、SAMAN M. Y. B. M.、MAN M. B.、HERAWAN T. 和 HAMDAN A. R. 增量式模型：通过基准案例研究实现。在：SOH P.、WOO W.、SULAIMAN H.、OTHMAN M. 和 SAAT M.（编辑）机器学习和信号处理方面的进展。电气工程讲义，卷。387施普林格，湛，2016：35-46。https://doi.org/10.1007/978-3-319-32213-1_4

[11] BAKAR W. A. W. A.、MAN M.、MAN M. 和 ABDULLAH Z. 我-埃克拉：在频繁项集挖掘中通过增量方法提高埃克拉的性能。泰尔康尼卡（电信、计算、电子和控制），2020，18（1）：562-570。https://doi.org/10.12928/telkomnika.v18i1.13497

[12] SABRI I. A. A., & MAN M. 使用威迪模型提高DOM在半结构化数据提取中的性能。印度尼西亚电气工程与计算机科学杂志, 2018, 9(3): 752-763. https://doi.org/10.11591/IJEECS.V9.I3.PP752-763

[13] BAKAR W. A. W. A.、JALIL M. A.、MAN

M.、ABDULLAH Z. 和 MOHD F. 后差异集：一种用于频繁项集挖掘的埃克拉类算法。国际工程与技术杂志, 2018, 7(2.28): 197-199. https://doi.org/10.14419/ijet.v7i2.28.12911
[14] RUFF B. 如何计算阻抗。wikiHow，2022年。https://www.wikihow.com/calculate-impedance
[15] JUSOH J. A., 和 MAN M. 修改iEclat算法以进行不频繁模式挖掘。高级科学快报，2018，24（3）：1876-1880。https://doi.org/10.1166/ASL.2018.11180
[16] YUSOF M. K. 和 MAN M. JSON用于大数据中的数据检索的效率。印度尼西亚电气工程与计算机科学杂志, 2017, 7(1): 250-262. https://doi.org/10.11591/IJEECS.V7.I1.PP250-262
[17] YUSOF M. K. 和 MAN M. JSON方法用于数据提取和查询检索的效率。印度尼西亚电气工程与计算机科学杂志, 2016, 4(1): 203-214. http://doi.org/10.11591/ijeecs.v4.i1.pp203-214
[18] AL-AMRI R.、MURUGESAN R. K.、MAN M.、ABDULATEEF A. F.、AL-SHARAFI M. A. 和 ALKAHTANI A. A. 用于物联网数据异常检测的机器学习和深度学习技术综述。应用科学, 2021, 11(12): 5320. https://doi.org/10.3390/app11125320
[19] ALQATAN S.、NOOR N. M. M.、MAN M. 和 MOHEMAD R. 约旦中小型旅游企业(中小型企业)中提高客户对移动商务信任的成功因素的实证研究。理论与应用信息技术学报, 2016, 83(3): 373-398. http://www.jatit.org/volumes/vol83no3/8vol83no3.pdf