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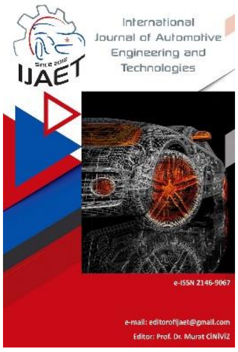

Original Research Article

IoT based a low cost battery monitoring system using ESP8266 and Arduino IoT cloud platform

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ABSTRACT

It is crucial to ensure the longevity of batteries in electric and hybrid vehicles in order to solidify their position in the market. Monitoring the life, capacity, and health of battery pack has become a major concern for users. The proper functioning and long-term durability of electric and hybrid vehicle batteries depend on accurately assessing their properties. In this study, a 6S battery module was created using NCR18650PF 3300mAh 3.7 V Li-ion batteries, which are increasingly used in electric and hybrid systems. Battery voltage, current, and surface temperature data of the battery module were collected during 500 charge-discharge cycles. Obtained charge-discharge profile, retainable capacity change rates, and the health and charge status of the battery were processed. The collected data showed the expected decrease in charge discharge profiles as documented in the literature. Upon reaching 500 charging cycles, the maintainable capacity of the battery module decreased by 70% compared to its initial state, indicating that the battery module had reached the end of its life. A program was developed using the Arduino IoT cloud system based on the charge-discharge profile and sustainable capacity change data obtained from battery characteristics. The predictions for battery health and state of charge based on the collected sensor data were processed and transferred to the interface in a way that allowed the end user to visualize it. The battery SOC, SOH, temperature, charge-discharge current, and terminal voltage data were displayed in the mobile application via the Arduino IOT Cloud platform with the ESP8266 Arduino card during daily use of the battery module. As a result, a successful module that can provide IoT communication on a lithium-ion battery pack was obtained. Thanks to the developed module, the expected life of the lithium-ion battery pack can be monitored even remotely, as long as it is connected to the internet.

Keywords: Battery State of Health, Battery State of Charge, Electric Vehicle, IoT Cloud, ESP8266.

1. Introduction

Over the years, the use of fuel-fueled vehicles has been a major factor in increasing air pollution on the planet. The emissions released by fuel vehicles increase the formation of greenhouse gases, causing the hole in the ozone layer to deteriorate. Climate change on the planet due to the conditions of the hole in the layer is one of the obvious consequences seen today [1]. Vehicles have a place in most of our daily lives in terms of transportation and comfort, and their use is a necessity. The electric vehicle project has reemerged because diesel and gasoline cycle processes do not pollute the environment and reduce oil reserves.

Electric vehicles are environmentally friendly because they have less carbon emissions compared to fossil fuel vehicles. Additionally, electric vehicles are a sustainable option due to their energy efficiency and low operating costs [1]. In electric vehicles, the DC motor transmits the drive to all four wheels using the stored electricity needed by the DC motor from the battery pack. They do not harm nature with their zero emission values during operation, but also provide a quiet and comfortable driving opportunity. However, for the development and use of the electric vehicle market to increase, users' concerns about range, rechargeability and battery life should be eliminated [2, 3]. Today, the most suitable battery type for storing the electrical energy needed by an electric vehicle is Li-ion batteries. Although Li-ion batteries are the most efficient, they need improvement. For the use of Li-ion batteries, the cost must decrease, and it is of great importance to be able to estimate batteries [4, 5]. It is difficult to predict battery life in this process because the life of Li-ion batteries can vary depending on the driver's driving style, charge-discharge cycles and the driver's charging habits [6,7].

In order to make a comment about the remaining healthy life of the batteries, instantaneous state of health (SOH) data must be known. Data measurements are made on the battery pack for battery SOH predictions [8]. Applications with real-time measurements are known as direct measurement techniques in literature. Direct measurement techniques include specific measurement techniques such as Ah counting, capacity testing, internal resistance measurement and electrochemical impedance spectroscopy [9 - 11]. Ah counting method can also be seen as Coulomb counting method in some sources. It is one of the most used experimental techniques today when the health status of a battery or batteries is desired to be estimated experimentally. In the Ah counting method, the current supplied to the battery during charging and the current drawn from the battery during discharge are checked [9]. Thus, the instantaneous capacity of the battery can be estimated. In the Ah counting method, it is important for the consistency of the method that the battery enters the charge-discharge cycle in an environment close to room temperature and is charged and discharged with currents that are not very variable. Measurements made and data collected in electric vehicle battery systems are generally used to control system operation. With the measurements performed, SOH and instantaneous state of charge (SOC) calculations of the batteries are made [8]. This information obtained can also be used to examine the system’s efficiency within a certain period of time and to increase the future performance of the system. Real-time measurement and analysis become important in terms of timely intervention to malfunctions that may occur in electric vehicle systems. It is also clear that real-time measurement and monitoring systems are needed in hybrid vehicle systems with multiple sources [12 - 14].

In the literature, the regulation and evaluation of the electric vehicle battery system [6, 15], tracking of battery charge amounts [16 - 18] and plug-in battery systems are mentioned in the literature. Data collection systems are known to measure stress and oxidation in systems such as hybrid and electric vehicles [19, 20]. The common features of these records are the use of data records to obtain measurement data and the analysis of these records by transmitting them to computers at certain periods. In this way, different battery characteristic data and counting methods were obtained from the abundances found in the literature, and 500 cycles of real-time charge-discharge expression were carried out during the current count. Data regarding battery current, battery voltage, battery properties and environmental temperature were measured with relevant sensors. With the operating data measurement system, fault errors, battery charge, health and charge state change and battery characteristics have been obtained, and an infrastructure of the cells is available for life estimation programming.

Arduino IoT Cloud is a cloud-based platform developed by Arduino. This platform, which supports various hardware such as Arduino MKR family boards, Arduino Nano family boards, ESP32 and ESP8266 based boards, facilitates the development of IoT projects. It is also possible to remotely update the project with Arduino IOT Cloud, which is a very easy-to-use platform where devices can be connected, data can be visualized, and the project can be controlled from anywhere. It also offers the opportunity to use the control panel created for the project on either a computer or mobile devices [21].

The Internet of Things (IoT) has revolutionized various domains, including agriculture, energy management, and infrastructure digitalization. Arduino, a popular microcontroller platform, has been extensively used in IoT applications due to its versatility and ease of programming [22]. The integration of Arduino with IoT cloud platforms has enabled real-time data tracking and monitoring in diverse applications [23, 24]. Additionally, the combination of Arduino with cloud computing has expanded the scope of IoT applications, enhancing its capabilities and enabling secure self-configuration of embedded devices [25, 26].

In the context of smart agriculture, Arduino-based IoT systems have been employed for automatic plant watering and environmental monitoring [27, 28]. These systems utilize Arduino microcontrollers to collect data from sensors and transmit it to the cloud for further analysis and decision-making. Furthermore, in the domain of energy management, IoT solutions based on Arduino have been developed for monitoring and controlling electrical energy consumption [29]. These systems enable users to track power consumption in real-time and take measures to conserve energy.

Moreover, the use of Arduino in IoT applications extends to infrastructure digitalization, where it has been integrated with cloud platforms for real-time monitoring of production processes and supply chain maintenance [30]. This integration facilitates the analysis of product life cycles and enhances business models through efficient provisioning and marketing strategies.

The seamless integration of Arduino with IoT cloud platforms has also been leveraged in environmental monitoring systems, such as pollution detection and pressure monitoring [31, 32]. These systems utilize Arduino devices to collect environmental data and transfer it to cloud databases for analysis and visualization. Additionally, the combination of Arduino with cloud computing has significantly enhanced the growth of IoT by ensuring and supporting the quality of service for IoT applications [33]. Many studies in the literature collectively emphasize the potential of Arduino-based IoT systems in monitoring and managing battery-related parameters, such as performance, usage, and environmental conditions, through cloud integration. The utilization of IoT for battery monitoring systems holds significant promise in enhancing the efficiency and reliability of various applications, including electric vehicles, energy management, and environmental monitoring.

The integration of Arduino with IoT cloud platforms has been widely explored in the context of battery monitoring systems Astutiningtyas et al. demonstrated the use of Arduino and cloud for real-time data tracking from a crop field, showcasing the potential for monitoring and controlling environmental parameters, including battery status [22]. Furthermore, the work by focused specifically on an IoT-based battery monitoring system for electric vehicles, emphasizing the relevance of IoT in battery management and maintenance [34]. Additionally, Kezhiyur et al. presented a system for monitoring and controlling electrical energy consumption using IoT, highlighting the applicability of IoT in managing power resources, including battery usage [24]. Moreover, Rusimamto et al. implemented an Arduino-based temperature monitoring system, which can be extended to include battery temperature and performance monitoring in IoT applications [35].

In summary, the integration of Arduino with IoT cloud platforms has facilitated the development of diverse IoT applications, ranging from smart agriculture and energy management to infrastructure digitalization and environmental monitoring. This integration has not only expanded the capabilities of IoT systems but has also contributed to the efficient and secure deployment of IoT solutions. The integration of Arduino with IoT cloud platforms offers a robust foundation for developing advanced battery monitoring systems, enabling real-time data tracking, analysis, and decision-making to ensure optimal battery performance and longevity.

2. Materials and Methods

2.1. Charging and discharging characteristics of the battery pack

During the creation of the battery pack for the analysis of battery characteristics, 18650 NCR 3300 mAh 3.7 V Li-ion battery cells of the Panasonic brand and 2 pieces of 3-slot plastic Liion battery beds were used to create a 6-series battery pack from Li-ion battery cells. The capacity of the created battery model is 3300 mAh and the terminal voltage is 25.2 V. HX-6S12A brand battery management system (BMS) was used to protect the battery pack and ensure balance between cells. This NCR18650PF type battery produced by Panasonic can typically provide efficiency for 500 charge-discharge cycles. Panasonic NCR18650PF is a cylindrical battery based on Li-ion battery technology. These Li-ion batteries are generally available at a nominal voltage of 3.7 V. While the maximum voltage of the battery is 4.2 V, the cut-off voltage during the discharge process is 2.5 V. In addition, the maximum continuous discharge current of the battery is 3.5 A [37].

A battery charging voltage of 25.2 V was obtained by using a 36 V DC power supply and XL4015 current adjustable DC/DC converter circuit in the charging circuit setup from the charge discharge current counting and temperature measurement data reading circuits. The maximum current on the XL4015 was set to 1.65 A to charge the created battery pack at a rate of 0.5 C. The output voltage of the XL4015 module can also be increased to 25.2 V by fixing it at 25.2 V which is the charging voltage of the battery pack. The battery pack is charged to the full charge voltage of 25.2 V in the charging cycle. The probe of the temperature sensor is fixed on the surface of the battery pack. The ACS712 current sensor is connected to the Arduino Uno board to read the temperature sensor and current data. In order to discharge the battery pack with 4 A, a load bank consisting of 6 12 V 21 W bulbs was created. While creating the load bank, 3 parallel circuits were established with 2 serial bulb connections to obtain 24 V voltage, and it was observed that the created load bank drew 4 A current from the battery, corresponding to a discharge rate of 6/5 C. In the discharge cycle, the battery pack was discharged to the cut-off voltage of 19.2 V, and when the cut-off voltage was reached, the discharge cycle was terminated by the battery management system (BMS). The surface temperature of the battery and the current drawn during discharge were transferred to the computer environment.

Battery surface temperature data taken from the temperature sensor and charge-discharge current data taken from the current sensor were transferred to the computer and converted into a txt file. Figure 1 shows the charge-discharge current counting circuits, and Figure 2 shows the txt file where the battery data is recorded.

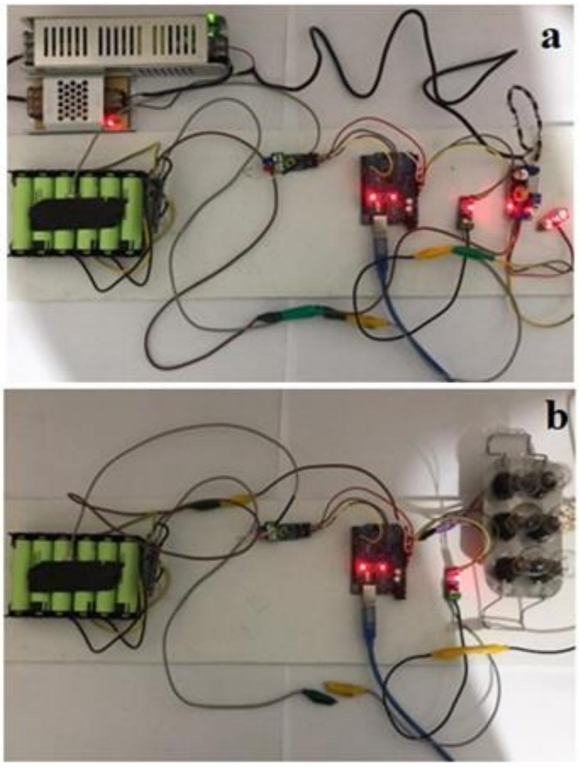

Figure 1. (a) Charging, (b) discharging current counting circuit.

After the initial SOC value was determined, the battery was subjected to successive charging and discharging cycles, and the instantaneous SOC status was monitored according to the measured current, voltage and temperature values in these cycles, and the capacity value of the battery at the end of each charge-discharge cycle was calculated. The algorithm for the charge discharge cycle life is given in Figure 3.

After completing 500 charge-discharge cycles, the data for each cycle was transferred to Excel. Capacity calculations were then performed for each cycle, and two separate graphs were created to show the capacity change during charging and discharging using the calculated capacity data. The capacity data were used to calculate the capacity change using Equation 1, and the change in capacity was expressed as a percentage.

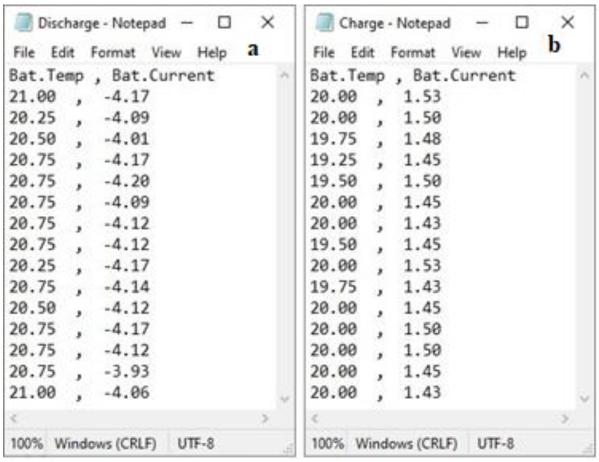

Figure 2. txt file of (a) discharge current, (b) charging current and surface temperature data

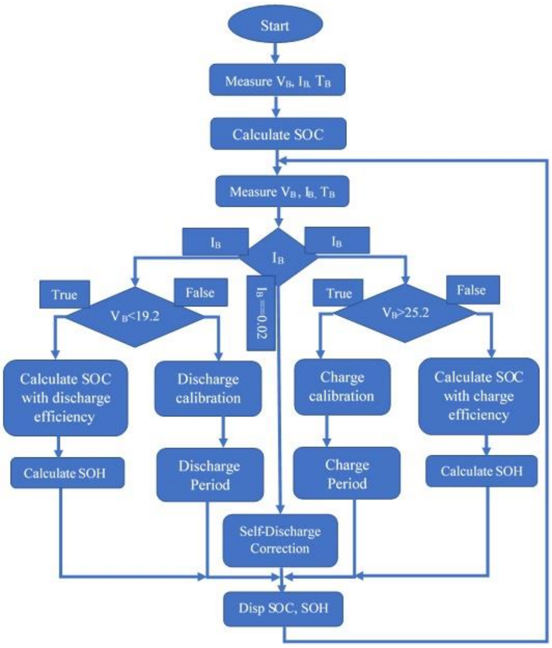

Figure 3. Flowchart of battery charge-discharge cycle

$$SOH(\%) = \frac{Holdable\ Capacity}{Initial\ Capacity} x100 \quad (1)$$

The temperature sensor installed on MAX 6675 was utilized to continuously measure the battery surface temperatures over 500 cycles. The temperature data was recorded and transferred to an Excel spreadsheet, enabling analysis of both current temperature readings and temperature changes during each cycle.

2.2. Determination of the battery pack characteristics

Ensuring the estimated decrease in the charging and carrying capacity of the battery at the end of 500 cycles. It was observed that the initial charging capacity of 3367.21 mAh decreased to 2513.94 mAh when the 500th cycle was reached. On the other hand, the results of 1972.93 mAh achieved in the last cycle of this battery model with an initial performance of 2954.05 mAh were revealed. It has been observed that charging and power capacities decrease after the 150th cycle. In Figure 4, the changing of the charging capacity and in Figure 5, the change graphs of the discharging capacity were shown.

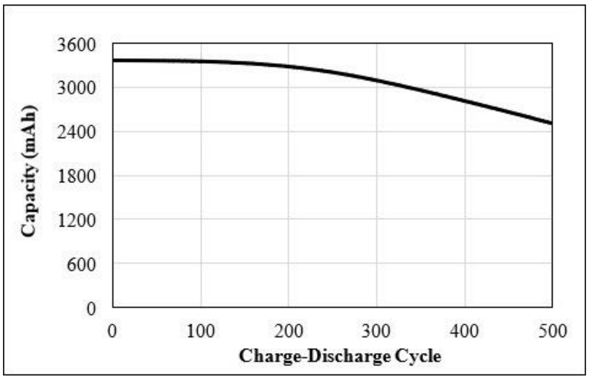

Figure 4. Change of charging capacity depending on the cycle

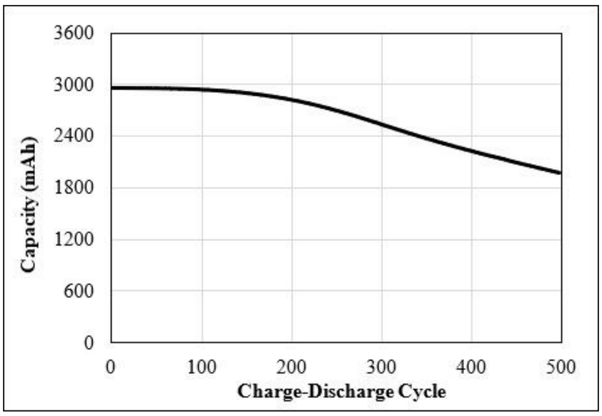

Figure 5. Change of discharging capacity depending on the cycle

As a result of all cycles, rechargeable capacity decreased to 74.66% and early discharge capacity decreased to 66.70%. According to the information given in the literature, it is accepted that the battery pack reaches EoL (end of life) at 70% capacity, that is, when its capacity decreases [38], and this situation is observed at a certain level. 66.70% with 500 cycles of the battery model used effectively. Table 1 shows the percentage changes of charging and power capacities according to certain cycles.

Table 1. Percentage changes of capacities depending on the cycle

Cycle	Charge (%)	Discharge (%)
0	100.00	100.00
50	99.90	99.87
100	99.61	99.37
150	98.90	98.03
200	97.52	95.43
250	95.21	91.29
300	91.94	85.90
350	87,98	80.38
400	83.67	75.44
450	79.19	70.93
500	74.66	66.70

Battery efficiency is obtained by dividing the discharge capacity by the charging capacity in the relevant charge-discharge cycle, as seen in Equation 2. The battery pack, which had an efficiency of 87.73% in the first cycle, reached the end of its life with an efficiency of 78.48% when it reached the last cycle, the 500th cycle. Figure 6 shows the change graph of battery efficiency depending on the number of cycles.

$$Battery\ Efficiency = \frac{Holdable\ Capacity}{Initial\ Capacity} x100 \quad (2)$$

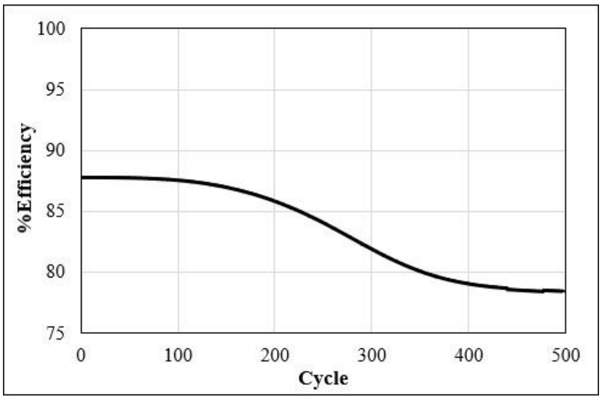

Figure 6. Battery efficiency depending on the number of cycles

It was observed that the battery surface temperature started the discharging phase at 25°C and rose to 45°C during discharging. At the end of the discharge process, the battery pack reached 45°C and were recharged at the same temperature, and when reached within the charging period, the surface temperature reduced to room temperature. Although the charging and discharging times were reduced, the battery surface temperature increased to 45°C during discharge process. It was also observed that, following the completion of the 300th charging phase, the battery was charged to capacity before the battery surface temperature had reached room temperature.

In addition to obtaining the current data and capacity values of each cycle transferred to the Excel environment, the charge curve profile of the relevant cycle was obtained. In the first charging phase of the battery, the CC (constant current) period continued for 2100 s, and then the charging was completed with the CV (constant voltage) period for 1600 s. It was observed that the CC period, which was 2100 seconds in the first charge, decreased to 1515 seconds when the last cycle was reached, while it reached 2500 seconds in the CV period. As expected, the duration of the discharge phase decreased, but no change was observed in the currents. Figure 7 shows the charge profile curves of 3 different cycles.

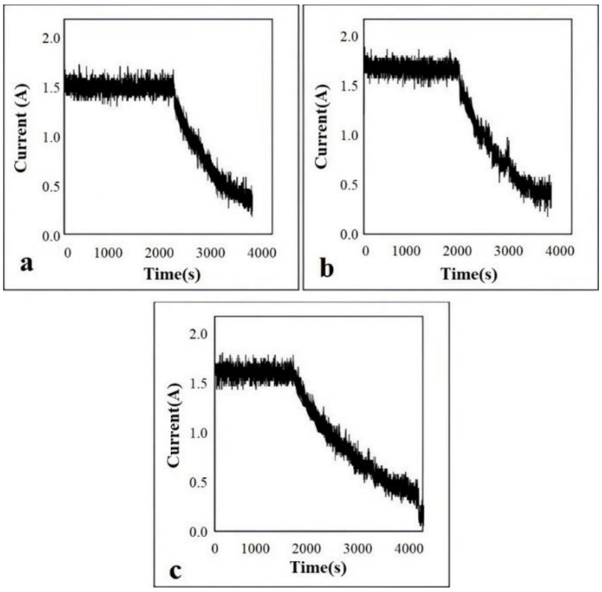

Figure 7. Charge profile graphs based on cycles; a: 1st cycle, b: 250th cycle, c: 500th cycle

2.3. Monitoring of the battery operating parameters on mobile interface

Battery monitoring circuit update has been properly communicated with Arduino IoT Cloud. Battery pack terminal voltage, charging and current currents, battery temperatures and battery SOH and SOC values were calculated remotely based on these data are also kept in the charging or discharging mode of the battery. The electronic circuit diagram of the battery monitoring system created with ESP8266 is shown in Figure 8. The electronic circuit hardware implementation of the system is shown in Figure 9. The data received from the battery during the charge-discharge cycle is transferred and visualized on the mobile interface through IoT, as depicted in Figure 10. Table 2 provides a comparison of the total cost, the developed low-cost battery monitoring system and the average price of an equivalent device available on the market. The developed low-cost battery monitoring system, as presented in this study, is capable of monitoring battery parameters such as the battery SOC, SOH, temperature, charge-discharge current, and terminal voltage data. All related data were displayed in the mobile application via the Arduino IOT Cloud platform with the ESP8266 Arduino card during daily use of the battery module.

3. Conclusion

In the study, it is carried out, one of the biggest questions of electric and hybrid vehicle users was monitored Li-ion battery data with a mobile interface via Arduino IOT Cloud. The study is based on obtaining characteristic data of the battery module in an electric and hybrid vehicle battery pack and determining the battery health status for each cycle with the obtained data. The extraction process of battery characteristic data lasted for 500 charge-discharge cycles at room temperature. The battery pack completed its charging periods at 25℃ room temperature throughout its healthy life and it was observed to warm up to 45℃ at the end of the discharge processes.

When the collected data were examined, it was observed that the instantaneous charge state, instantaneous health state and battery efficiency values decreased as expected, with the obtained charge-discharge profiles and cycle-related capacity loss, as in the literature. It was observed that when 500 charge-discharge cycles were reached, the retainable capacity of the battery module dropped below 70% compared to the initial capacity, reaching the end of its usable life. Battery efficiency was obtained by dividing the discharge capacity obtained for each cycle by the charging capacity. It was observed that the efficiency of the battery pack, which was 87.73% in the first cycle, decreased to 78.48% when the last cycle was reached.

As a result, a cost-effective module has been developed that enables IoT communication with lithium-ion battery packs. With this innovative module, it is now possible to predict the lifetime of the lithium-ion battery pack, even when it is located remotely, as long as it is connected to the internet.

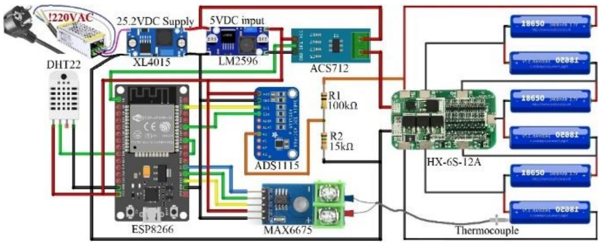

Figure 8. Electronic circuit diagram of battery tracking system functioning with IoT Cloud platform.

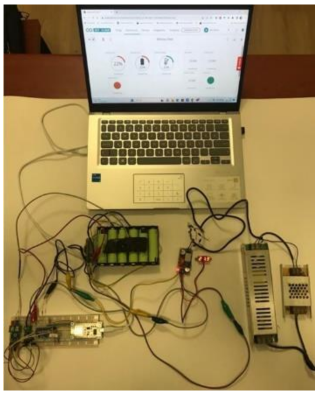

Figure 9. Hardware implemention of system design

Figure 10. Arduino IoT Cloud mobile interface; a) Charging time, b) Discharging time.

Table 2. The total cost of the battery monitoring system and market price comparison

Component	Description	Number	Price (₺)	Total (₺)
ESP8266	To communicate with the Arduino Cloud	1	100	100
DHT22	To obtain working environment humidity and temperature information	1	80	80
ADS1115	To obtain working environment humidity and temperature information	1	90	90
ACS712	To read battery pack charge/discharge currents	1	50	50
LM2596	To convert the 36VDC voltage at the power supply output to 5VDC	1	40	40
15kΩ/100kΩ Res.	To divide the battery terminal voltage to the appropriate voltage level for the ADS1115 input	1	0.30	0.30
MAX6675 Thermocouple	To monitor battery pack surface temperature	1	95	95
36VDC 5A Power Supply	For power supply of battery pack and electronic circuit	1	200	200
				655.30 ₺
Average price of equivalent device commercially available in the market [39].				**10985 ₺**

This study has provided valuable insights for predicting the life and health of Li-ion battery packs used in electric and hybrid vehicles. The results obtained enhance our understanding of Li-ion battery performance over time, which supports the advancement of battery technology and efforts to improve the overall performance of electric and hybrid vehicles.

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Credit authorship contribution statement

The contribution rates of the authors to the study are equal.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared toinfluence the work reported in this paper.

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