A Comprehensive Review for Enhancing Electric Vehicle Performance: An IoT-Based Approach for Battery Monitoring and Management

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***Abstract*—Electrical vehicle batteries are damaged due to overcharging or over-discharging, so they need to precisely estimate the State of Charge (SoC) to extend their lifespan and protect the connected components they power. This review presents Enhancing Electric vehicle (EV) performance based on Internet of Things (IoT) for battery management and monitoring system. The IoT technology display essential information required about the battery's status, battery capacity and the charging and consuming current. Thus, this system integrates sensors to monitor several battery properties, such as voltage, current, temperature, SoC, and State of Health (SoH). The sensor data are forwarded to a central IoT platform, where sophisticated analytics and machine learning algorithms can be utilized to evaluate battery condition and forecast the battery's Remaining Usable Life (RUL). The system sounds an alarm for prompt replacement when a battery is nearing the end of its life or begins to show indications of degradation.**

***Keywords*—Battery Monitoring, Battery Replacement, Battery-Operated Vehicles, Electric Vehicles, IoT, Machine Learning, Predictive Maintenance**

I. INTRODUCTION

Using green energy is becoming more and more important in today's society. Because of this, a number of firms are looking for gasoline substitutes for other energy sources for both private and public transportation. Using electrical energy sources might lead to less pollution, improving the environment. In addition, EVs have a lot of advantages in terms of energy and conservation of the environment. Nowadays, electric vehicles are the greenest choice [1]. Electric car discovery began many years ago. There have been around six distinct generations of electric car development since then. Then, it was challenging to produce electric cars, and in order for a car to have a decent mileage, a lot of lead-acid batteries had to be utilized, which significantly increased the weight of these vehicles [2].Depending on the needs, a battery's several cells can be linked in parallel or series. Since thermodynamic processes occur inside the cell, the cell voltage was challenging to measure. CCV (closed-circuit voltage) and OVC (open-circuit voltage) values are therefore employed [3].Developing an exact battery model to calculate the SoC and track its performance was the fundamental task of battery management. To develop the effectiveness of the Battery Management System (BMS), researchers have created a variety of battery modelling and state estimation techniques [4]. In order to solve environmental challenges and future perspectives depends substitute measures for long-term growth, new approaches to design of batteries, pathways for recycling, and reverse logistics have recently been offered [5]. It was easier to find the charging station and prevent congestion by keeping an eye on the information about the charging stations and the vehicle requirements to reach the station depending on the battery level. The mesh network based on radio frequency identification monitoring will be a good option. The information will be transmitted and received using electromagnetic waves (EM waves), allowing us to improve the charging infrastructure in accordance with the requirements [6].Fast charging and deep draining, however, have the potential to harm a battery's capacity and performance [7].The EV Monitoring System, which is built on the IoT, is a complete framework that utilizes data analytics, sensors, and IoT device interconnectivity to improve and monitor many aspects of electric vehicle performance. Fundamentally, the system seeks to handle major issues that EV stakeholders confront, such as optimizing vehicle performance, managing batteries, making use of the charging infrastructure, and managing the fleet as a whole [8]. In order to provide a direct line of communication among the energy community's cloud infrastructure and the battery storage systems (BSS) that come under, an IoT approach that gets around the present method's drawbacks is suggested in this review. The recommended IoT resolution consists of a cloud-based architecture and a home gateway, avoiding the use of cloud infrastructures of BSS manufacturers [9]. IoT devices are now enabling a several RT appliances, including innovative media, home automation, energy management, smart manufacturing, intelligent healthcare and medicine, smart buildings, smart buildings, smart buildings, and so on. There are numerous IoT devices on the market for the aforementioned purposes. The type of IoT device utilized depends on the application and the task at hand. But since they're so simple to use and operate, Arduino and Raspberry Pi are the most popular IoT gadgets [10].

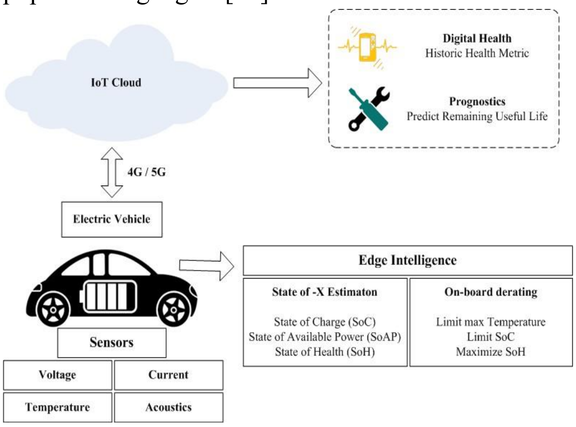

Figure 1.1: Performance of EV based on IoT using BMS

II. PERFORMANCE ENHANCEMENT METHOD

A. Power-Train Method

An EV power-train in [11] consists of a battery, an electromotor, a Continuously Variable Transmission (CVT), and other transmission components. Based on the direction of power flow inside the powertrain, the driving modes of an electric vehicle were categorized into three primary categories: Uniform Motion Mode (UMM), Deceleration Mode (DM), and Acceleration Mode (AM). A positive power flow direction and zero braking force are present during AM and UMM. The electromotor receives its stored electric energy from the battery, which serves as an energy supply source. The CVT handles the electric energy once it has been transformed into the mechanical energy of rotation for the electromotor. By modifying its speed ratio, the CVT modifies the torque and speed of the spinning mechanical energy. It then sends this energy to other broadcast devices, for instance, the final reduction drive, which drives the wheels and enables an electric vehicle to operate. However, because energy is used to charge the battery that is transferred via the electromotor, CVT, and other broadcast systems one after another, the power flow direction in the DM is opposite, and the braking force is not zero.

B. Batteries Thermal Management

Temperature variations and both low and high operating temperatures have a negative influence on Lithium-Ion Batteries (LIB). Consequently, as stated in [12], maintaining the whole power battery pack's temperature within a tolerable range is the major objective of the BTMS. Apart from thermal performance, several additional factors need to be considered, including energy usage, system cost, scalability, feasibility, and compatibility. In general, BTMS shouldn't account for more than 20% of the battery pack's total weight. The structures for managing heat also shouldn't interfering with wires, bus bars, or pack shells. The highest temperature that should be maintained below 40°C while cooling is effective, preferably below 35°C. In low-temperature situations, the lowest temperature must be higher than 15°C. To guarantee temperature consistency, the battery packs and modules must have a temperature differential of no more than 5°C. The BTMS is classified as Phase Change Material (PCM), Heat Pipe (HP), liquid, air, or Thermoelectric Cooler (TEC), among other things. Other divisions include of heating or cooling, parallel or series, passive or active. Pumps and fans in an active system require more energy to run; these systems are normally used with liquid and air cooling approaches. In passive systems, the heat from the battery surface must be removed via PCM or HP. Active systems are complicated but often more effectual in dissipating heat. Whereas HP-based systems are utilized for aim of PCM-based passive systems

III. CRITICAL ROLE OF BATTERY MANAGEMENT

A. State Performance Characteristics

The rapid advancements in data storage, communication technology, and computing power

[13] have led to increased interest in SoC, SoH, and RUL estimates depends on ML methods. The performance attributes of several machine learning instruments utilized in Li-ion-BMS for state and co-state estimation. When applying machine learning (ML) techniques to forecast states, the following five steps are frequently incorporated in the implementation process: feature removal growth, model validation, training set, test set, and offline measurement. Using offline experiment procedures, batteries' temperature, voltage, and current are monitored and recorded. A set of health features with "k" dimensions that are extracted from the unique compute data sets then serves as a representation of the pertinent elements during the decline. The SOH output is predicted by the training of the ML technique with different inputs of health variables, which also includes fine-tuning and refining the ML technique parameters. SOH is anticipated to be the final, and the integrated model has been verified. With the development of advanced machine learning algorithms, the predicted precision, efficiency of learning, generalization, and convergence rate have all greatly increased. While RUL and SOH are related linearly, SOC and SOH are fully linked in a nonlinear manner. For battery management to be effective, SOH and RUL must be estimated and managed accurately. Battery aging is indicated by SOH, or the highest discharge capacity to the battery's rated capability since the highest discharge capability is a marker of aging batteries. SOH is 100% for a newly formed cell that has not degraded. A cell is considered to be at the end of its useful life when the SOH value falls below a certain threshold. How much functional life is left depends on how long one has left till death.

B. STATE OF CHARGE

The quantity of energy left in a battery is measured by its SoC [14].According to physical definitions, a battery's remaining energy (ψ) is equivalent to the cathode's average LI-ion concentration. (C_{savg}) divided by the greatest concentration that is feasible.

$$\Psi = C_{savg} / C_{smax} \quad (1)$$

Theoretically, $\psi = 0$ and $\psi = 100$ is possible; It is not practical, though, as removing an excessive amount of Li- ion from the cathode may harm the structure and speed up deterioration. Consequently, a ψ window is definite for LIB. Here $\psi_{0\%} > 0$ and$\psi_{100\%} < 1$. The defined ψ windows may now be used to specify the SoC.

$$SoC = (\Psi k - \Psi 0\%)/(\Psi 100\% - \Psi 0\%)(2)$$

Here ψ_k signifies the battery's remaining energy at any given time k. The concentration of Li-ions cannot be directly monitored, therefore while this characterization of SoC is valid theoretically, it is not physically practicable for a BMS to compute. Consequently, one has to define SoC in a way that does not depend directly on the concentration of Li-ions. Therefore, the LIB residual power ratio (C_r) to the maximum available capacity (C_a)may be used toexplain SoC (Equation (3)); (C_r) represents the remaining energy that the LIB may eventually exhaust; (C_r) is impacted by cyclic changes and the electrochemical degradation of LIBs;
(C_a) is the maximum load capacity that may be obtained under a variety of circumstances during the first cycle period; (C_a) cannot attain the specified power level. (C_{rated}) (i.e the manufacturer's LIB capability for continuous use). The significance of a LIB (C_a) depends on the current discharge volume and SoH.

$$Soc(t) = \left[\frac{Cr}{Ca}\right] * 100\% \ (3)$$

C. Estimation Of State Of Health

The SoH is a battery aging metric in [15]. It has to do with battery capacity, which can be as low as 80% for automotive use and as high as 100% for fresh batteries. The SoH measures how much a battery can hold fully charged compared to its stated capacity.

$$SoHc = \left(\frac{C}{Cn}\right) * 100\% \ (4)$$

The self-discharge rate, internal resistance, coulombic efficiency, and impedance of batteries have all been related to SoH. Internal resistance and battery capacity, which represent a battery's power and energy potential, respectively, are frequently used to calculate the SoH of a given battery. Preventing abrupt deterioration and probable failures of the battery can be aided by an accurate assessment of the SoH. A more accurate estimate of the SoH may result from more data.

D. Remaining Useful Life Prediction

A decreased amount of data leads to a worse prediction accuracy when employing time series approaches, as demonstrated in [16]. Another approach, which makes use of regression techniques, is to first ascertain the future factors and then predicts the SoH. Future values are forecasted employing the autoregressive integrated moving average (ARIMA) method if the parameters exhibit temporal patterns. Monte Carlo simulation is used to forecast future values when the factors, like driving behaviours, are random or unpredictable. It is possible to forecast the SoH using the regression models. When using simulated data. The internal battery parameters are predicted using the ARIMA model for simplicity's sake, while the SoH and RUL are predicted using Lasso regression.

E. Managing An Ev Battery Pack

The battery cells in a battery pack [17] can be linked in series or parallel. The voltage output of the cell is resolved by the count of cells in series, even if adding additional cells to the pack improves its capacity. The more charged cells will automatically discharge in the lowest voltage cell when the cells are put in parallel, balancing each other out. The BMS must balance them as if they are connected in a series, imbalance may develop with use. In addition, each cell in a series needs to be observed separately. It is not recommended to utilize the entire pack if even one cell leaves the safety window. The pack's cell structure is commonly described by the expression XS Y P, where Y is the count of cells in similar and X represent the count of branches connected in series. For instance, common topologies in commercial electric vehicles include 96S1P and 96S2P. Modern EV's divide their battery pack into modules, which are made up of a sequence of usually six to sixteen cells, to minimize the size of the wire harness. A board known as the Cell Sensor Unit (CSU), sometimes called the Cell Supervision Unit, is in charge of overseeing each module. It connects with the Master Control Unit (MCU) by an I2C, SPI, or UART daisy chain bus.In an electric vehicle application, the BMS is equipped with external connections that allow it to exchange data with other device, such as the engine controller, and to show information to the user on the dashboard. The controller area network, a popular option for in-car networking, is being used via this interface in today's EV.

F. Voltage Sensor Test

The battery was selected, its voltage values were varied, and the results of the battery measurement will show these differences. In this test, the battery's values were measured using a multimeter and compared with the values of the same battery that is connected to the voltage sensor circuit [18]. The goal is to display the differences and also the accuracy between both values in percentage.

Table 1: Voltage Measurement

SI No.	Voltage Measurement result		Accuracy Percentage (%)
	Voltage Sensor	Multimeter	
1	10.4	10.38	99.80
2	12.6	12.59	99.92

G. Temperature Sensor:

Because it determines the battery's present condition, the temperature of the battery is an extremely important metric. A high battery temperature is an obvious sign of instability, or more accurately, it shows how the battery behaves when its typical circumstances are not met. As seen in Figure 1.2, The LM35 temperature sensor uses a diode's basic principles to measure a known temperature. Everybody aware from semiconductor physics that a diode's voltage increases in response to temperature at a steady rate. If you take the voltage change and exactly magnify it, you can easily construct a voltage signal that is directly proportional to the ambient temperature.

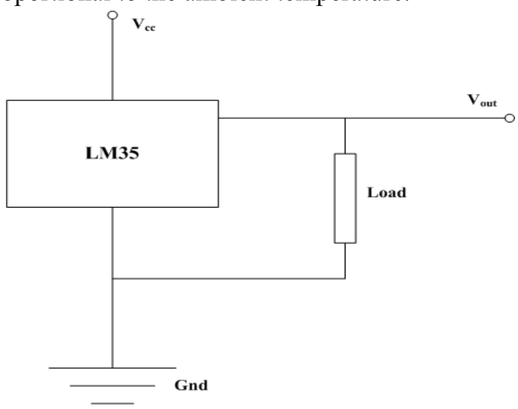

Figure 1.2: Temperature Sensor

VI. CHARGING TECHNIQUES

The battery pack is regarded as the EV's essential component. The relationship between cell temperature, charging time, and battery life was noted in many evaluations that concentrated on EV battery charging [19]. Increased charging current speeds up battery charging but shortens battery life. The battery's operating temperature should be high enough to prevent SEI layer formation and lithium plating. The applied charging methods for lithium-ion batteries are examined in relation to their charging voltage, current, duration, and cell temperature.

A. Constant Current

Throughout the charging process, the continuous current is kept up. This is where the predetermined value is set; charging stops as soon as it reaches that value. A high, continuous current was maintained to charge a battery quickly, but this will shorten its lifespan. On the other hand, a low current can prolong battery life but only charge the battery slowly. As a result, charging current affects battery health. A major problem with CC charging is figuring out the ideal charging current number to balance the duration of the battery's charge.

B. Constant Voltage

The charging procedure keeps the voltage at the predetermined constant. After the voltage is attained, the charger will only supply the minimum amount of current required to keep the battery at that voltage. A set point voltage that is too high will shorten battery life, while a low voltage prevents the battery from being fully charged. A steady current charge is kept when the battery voltage falls below the predetermined threshold. Lithium-ion batteries have a standard set point voltage of 4.2V.

VII. IOT FOR BATTERY MONITORING

The term IoT refers to the idea of a network of linked objects that allow for new types of communication both between objects and between humans. Since the Internet Boom has an impact on many facets of society, the 21st century is known as the "Internet Century" [20]. This profound truth creates possibilities for connecting all physical objects to exchange data. The IoT has become one of the most important and rapidly growing technologies of the twenty- first century thanks to the recent rapid growth of related technologies like computing and computer technology, information technology, and the infrastructure for communication and IT. IoT makes it possible for "Things" which include useful gadgets, instruments, detector, integrated systems, and so forth to grow intelligent and have Internet-based communication capabilities with people worldwide. By leveraging the Internet of anything, people may monitor and control anything from anywhere at any time. The following are some of the most significant and fascinating uses of IoT:

Intelligent Residences and Towns
Medical Surveillance
Environmental Surveillance
The Automobile Sector
Agriculture and Smart Industry
Control of Energy

In terms of information exchange and monitoring, integrating IoT into the BMS is also a helpful update. A basic, inexpensive system (in our example, a microcontroller-based BMS) may gather information about the operating circumstances and battery state. Subsequently, a more potent workstation can receive the data in order to carry out further sophisticated processing and analysis.

VIII. CLOUD COMPUTING

Both the communication technologies and the semiconductor industry have seen previously unheard-of advancements, exemplified by the next-generation and fifth- and sixth-generation network technologies in [21] EVs, communication, and cloud framework are the three main parts of the vehicular CC. Massive volumes of RT data will be collected by a local server and delivered to the CC center to complete sophisticated methods like data driven data mining, AI, and big data analysis. The enormous dataset cannot be processed by a local or onboard BMS in the time it takes with these solutions. The cloud BMS created a digital twin of battery systems and predicted the SOH, which illustrates capacity reduction and power fade brought on by aging, through resource integration and data interchange. A two-layer internet-distributed system was utilized for real-time global optimization through the use of CC technology and vehicle IoT. The CC platform may provide SOH prediction.

IX. WIRELESS BATTERY MONITORING SYSTEM

Reliable battery management is crucial in [22] for safety reasons. A number of things, such as aesthetic defects and battery degradation, can lead to battery failure. In that they don't save data in a database, manual battery monitoring systems are comparable to conventional battery monitoring systems. Still, the data collected in real time will be the only ones shown. Therefore, it is essential to implement wireless technologies in order to remotely monitor battery systems. Uninterruptible power supply

(UPS) is one of the many battery monitoring systems (BMS) that employ wireless communication that have been developed for the industry. UPS is crucial for maintaining power supply continuity for residential and commercial clients during power outages. A UPS's PLC-based battery health monitoring system uses ESP8266 modules and SCADA to monitor battery conditions and issue warning signals when the temperature rises too high or the batteries are in critical condition. Additionally, an ESP8266-based BMS for UPSs was created. This system may be employed to monitor the battery's temperature, voltage, and current. A UPS-BMS uses wireless communication to identify dead battery cells. The creation of a wirelessly communicative BMS for EV’s has also been the subject of several investigations. An electric vehicle's engine and battery charging systems were built using an ESP8266 module. The user gets an SMS when the battery health drops below a predetermined level. The user can then reply with an SMS to initiate the engine's charging process automatically. Electric vehicles with wireless battery monitoring systems employ a 2.4GHz radio communication technology. The modular design consists of the transmit module, which tracks batteries, and the controller module, which receives battery status information. ZigBee communication and point-to-point wireless topology were used in the development of a BMS for EV’s. ZigBee was selected because to its little power consumption, affordability, high dependability, and slow data rates. Their conclusion was that while wireless BMS’s are useful for EVs, they are not useful for managing battery temperature. Instead, they are primarily needed to balance the charge and prolong battery life. Electric vehicles (EVs) now have access to lithium-ion battery monitoring systems that use WiFi to gather and show battery characteristics such as temperature, voltage, and current on a smartphone. t appears that there is no automatic monitoring mechanism available to inform the customer about the battery's presentation depends on the previously reported study. Consequently, implementing IoT technology in tandem with a monitoring system may help improve defensive protection, guarantee battery quality, and raise user security.

X. BENEFITS OF IOT-BASED BMS

Real-Time Monitoring: Continuous data collection allows for immediate detection of anomalies, such as overheating or overcharging, which can prevent battery damage.

Predictive Maintenance: Data analytics can forecast potential failures and suggest proactive maintenance, reducing downtime and repair costs.

Enhanced Safety: Monitoring parameters like temperature and voltage helps in maintaining the battery within safe operating conditions, reducing the risk of accidents.

Optimized Performance: By understanding usage patterns and environmental impacts, the BMS can optimize charging cycles and improve the overall efficiency of the battery.

XI. CONCLUSION

The combination of IoT technology with EV-BMS presents noteworthy progress in terms of maximizing battery efficiency, augmenting security, and prolonging the life of EV batteries. IoT-based BMS can provide continuous monitoring of critical battery specifications like temperature, voltage, current, and SOC. This continuous monitoring enables immediate detection of anomalies and facilitates predictive maintenance, which can prevent potential failures and reduce downtime and maintenance costs.The benefits of an IoT-based BMS extend beyond just operational efficiency. Enhanced safety measures are achieved by maintaining batteries within safe operating conditions, reducing risks associated with overheating or overcharging. Furthermore, by understanding usage patterns and environmental impacts, the BMS can optimize charging cycles, thereby improving overall battery efficiency and vehicle performance. Future research and development should focus on overcoming the current implementation barriers, refining the technology, and exploring broader applications of IoT in other aspects of EV systems. By continuing to innovate and integrate IoT solutions, the EV industry can achieve significant advancements in performance, safety, and sustainability, causative to a greener and efficient change future.

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