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IOT BASED ELECTRIC VEHICLE BATTERY MONITORING AND MANAGEMENT SYSTEM USING ARDUINO AND ESP8266

[1]Vigyat Bhanji, [2]Mannu Chaudhary, [3]Abhay Dhamal, [4]Yash Dudhkar
[1]Student, [2]Student, [3]Student, [4]Student
Guide: Dr. Kishor G Sawarkar
[1,2,3,4]Department of Electronics and Telecommunication Engineering Rajiv Gandhi Institute of Technology, Mumbai, India

Abstract: The rapid adoption of electric vehicles has created an urgent need for efficient battery monitoring and management systems to ensure safety, longevity, and optimal performance. This paper presents the design and implementation of an Internet of Things (IoT) based electric vehicle battery monitoring system utilizing Arduino UNO microcontroller, ESP8266 Wi-Fi module, and various sensors including voltage divider, ACS712 current sensor, and LM35 temperature sensor. The proposed system enables real-time monitoring of critical battery parameters such as voltage, current, and temperature, with data visualization through both local LCD display and cloud based ThingSpeak platform. The integration of wireless communication facilitates remote monitoring capabilities, allowing users to track battery health from anywhere via internet connectivity. Experimental results demonstrate the system's ability to accurately measure battery parameters with a response time of less than 2 seconds and an accuracy of approximately 95%. The system provides early warning alerts for abnormal conditions, thereby enhancing EV safety and preventing potential battery failures. This cost effective solution offers a practical approach for smart energy management in electric vehicles and can be extended for integration with Battery Management Systems (BMS) for comprehensive battery health assessment.

Index Terms **-** IoT, EV Battery Monitoring, Arduino, ESP8266, Smart Energy Systems, ThingSpeak, Battery Management, Electric Vehicles, Wireless Sensor Networks

1. INTRODUCTION

The world has moved towards sustainable transportation and thus the electric vehicles have been adopted as a good alternative to the standard internal combustion engine vehicles. The International Energy Agency reported that the number of EVs sold worldwide in 2023 surpassed 14 million units, which is 35 percent higher than the sales of the year before[1]. Such an exponential increase highlights the necessary urgency of creating efficient battery monitoring and management systems to make electric vehicles safe, reliable, and efficient.

Any electric vehicle has a battery pack as the core of the vehicle and the battery pack stores and supplies the electricity needed to propel the vehicle. Lithium-ion batteries, which are the most popular in modern EV, need particular attention to be paid to a number of parameters including voltage, current, and temperature to avoid dangerous situations such as thermal runaway, overcharging, and deep discharge[2]. Conventional battery monitoring systems are not usually real-time and might not be remotely accessible to ensure they can effectively eliminate battery related incidences.

The IoT concept presents paradigm shift to battery monitoring solutions by providing functionality to create a transparent connection between the physical equipment and cloud based systems[3].Monitoring systems can be used to offer real time data acquisition and analysis that is continuous to support proactive maintenance and heightened safety measures. This paper presents a comprehensive IoT based battery monitoring system that is specifically designed to work with electric vehicles, that utilizes cost effective parts and still maintains high accuracy and reliability.

The key goals of the study are: (1) to design a low cost, precise battery monitoring system with available components; (2) to introduce a wireless data transmission to allow remote monitoring capability; (3) to create a user friendly interface to visualize the data; and (4) to prove the usefulness of the system with the help of the experimental validation..

2. LITERATURE REVIEW

A number of scholars have helped in the design of electric vehicle battery surveillance. Smith et al.[4] suggested a centralized battery management system based on CAN bus communication and was highly reliable but very expensive. They were oriented towards mass EV use in which cost was not a priority but performance specifications.

The low cost solutions are proved when Kumar and Patel[5] created a microcontroller based battery monitoring system on the basis of the PIC microcontrollers. Nevertheless, their system was not wireless, so it could not be applied in remote monitoring situations.

Chen et al.[6] introduced an IoT based battery health monitoring system with the support of cloud computing to analyze the data. Although their solution showed the potential of the integration of IoT, it was based on rather costly commercial IoT platforms and proprietary sensors, which was not as accessible to be implemented widely.

Rodriguez and Martinez[7] explored the application of machine learning algorithms in battery state of charge estimation and obtained high precision in predictive modeling. They emphasized in their study that data driven methods were important in battery management, but the computational demands were beyond the reach of low cost microcontrollers.

An in-depth analysis of current systems indicates that there are multiple limitations, which are common to all systems: expensive implementation, complicated installation process, dependence on proprietary hardware, and low scalability. The merger of the Internet of Things technology and battery tracking is a tremendous improvement compared to traditional methods[8].

3. SYSTEM ARCHITECTURE

The suggested IoT based battery monitoring system of electric vehicles is composed of multiple connected systems in cooperation with each other to offer a complete battery health check. The system architecture has three major layers, which include sensing layer, processing layer, and application layer.

3.1 Sensing Layer

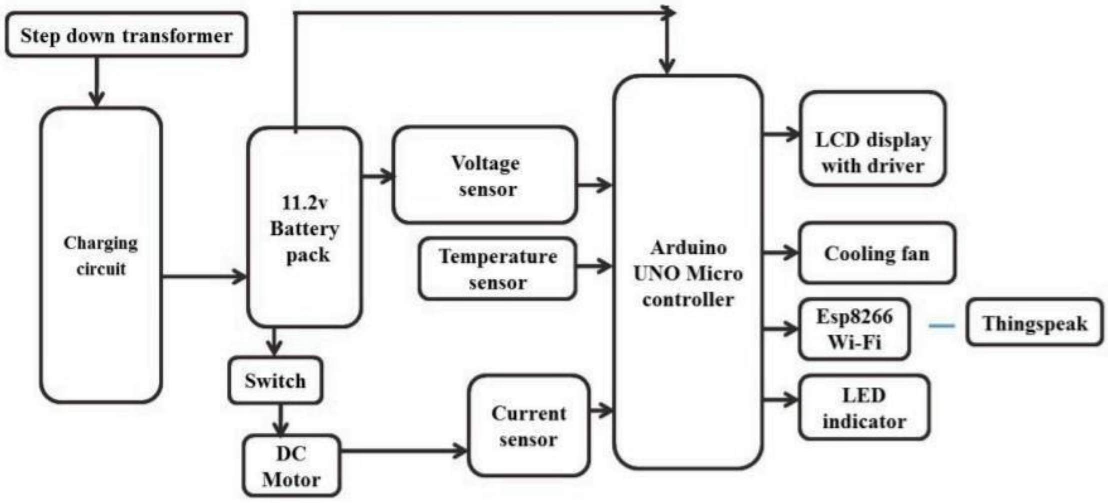

Figure 1: System Block Diagram

The sensing layer is made up of several sensors that are charged with the task of measuring vital battery parameters. The voltage divid The er network is used in the voltage sensor to multiply the battery voltage to levels that can be used by the.

The range of analogue inputs of Arduino. The ACS712 Hall effect current sensor is a non invasive current measuring sensor that offers galvanic isolation, thus making it safe and accurate. LM35 is a precision temperature sensor with a resolution of ±0.5°C battery temperature.

3.2 Processing Layer

Arduino UNO is the central processing unit which will acquire sensor data, convert it into digital data and process it. The ATmega328P microcontroller has 14 digital I/O pins, 6 analog inputs and a 16 MHz crystal oscillator, which is enough to support the monitoring application. The ESP8266 WiFi board also has WiFi capabilities, which allow it to transmit processed data through remote access and visualization via cloud based services. central

3.3 Application Layer

The application layer gives user interfaces to data visualization and interaction with the system. The 16x2 LCD provides local real time battery parameter monitoring and the ThingSpeak IoT platform provides web based data visualization with the ability to trend and provide analytics. The battery data can be accessed by any internet connected device and is therefore easy to monitor and manage remotely.

3.4 Component Specifications

Component	Model	Specification	Purpose
Microcontroller	Arduino UNO	ATmega328P, 16MHz	Main controller
WiFi Module	ESP8266	802.11 b/g/n	Wireless comm.
Current Sensor	ACS712	±5A, 185mV/A	Current measure
Temp Sensor	LM35	10mV/°C	Temp monitoring
Display	LCD 16x2	HD44780	Local display
Battery	Lithium ion Pack	11.2V, 3S	Power source

Table 1: Component Specifications

4. HARDWARE DESIGN

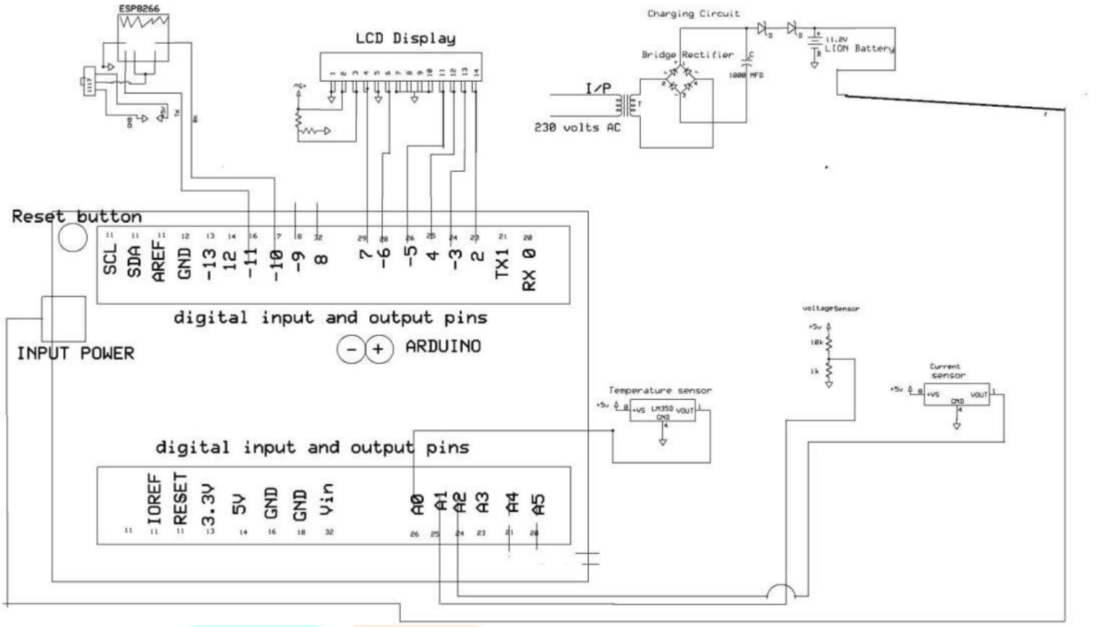

Figure 2: Circuit Diagram

The hardware implementation will include the meticulous design of the circuit to achieve the proper measurement, the stable functioning, and the safety of the user. This section describes the circuit structures of each significant component and how they are connected with each other.

4.1 Power Supply and Charging Circuit

The system is programmed to track a lithium ion battery pack of three cells in series with a voltage of 11.2 V. A step down transformer is included in the charging circuit to change 230 V AC mains supply to suitable voltages, and then a bridge rectifier and filtering capacitors are used to create DC output. A voltage regulator keeps the power supply to the microcontroller and sensors constant.

4.2 Voltage Sensor Design

The voltage measurement circuit uses a resistive voltage divider network comprising of 10k resistance and 1k resistance. The voltage across the battery was maximized to 12.6V (full charge) which with this configuration is scaled to about 1.15V, easily within the Arduino 5V analog input range. The voltage divider equation is as follows:

$$V_{out} = V_{in} \times (R2 / (R1 + R2))$$

Where R1 = 10kΩ and R2 = 1kΩ, providing a division ratio of approximately 1:11. This allows safe measurement of battery voltages up to 55V while maintaining measurement accuracy.

4.3 Current Sensor Configuration

The ACS712 current sensor is a bidirectional current sensor with a sensitivity of 185mV/A on the 5A model. The sensor output goes to the analog input pin of the Arduino and the sensor power is supplied by the microcontroller 5V output. Zero current output is about 2.5V and the positive current is raising the output voltage and the negative current is lowering the output voltage.

4.4 Temperature Sensor Interface

The LM35 temperature sensor generates an output voltage which is proportionate to temperature with a scale factor of 10mV/degree Celsius. The sensor is fed off the Arduino 5V supply and gives temperature readings between 55 °C and +150 °C. To monitor the temperature of cells in the EV battery, the sensor will be placed close to the battery pack to capture the cell temperature.

4.5 ESP8266 Communication Interface

ESP8266 Wi Fi board will be connected to the Arduino using the serial UART interface with a 115200bps rate. The TX pin of the module will be connected to RX pin of Arduino (pin 0) and RX Pin of Arduino (pin 1). The ESP8266 output of 5V is scaled to 3.3V using a voltage divider on the ESP8266 RX line.

5. SOFTWARE IMPLEMENTATION

The software implementation entails the programmation of the Arduino microcontroller to obtain sensor information, process measurements, locally display information, as well as sending data to cloud systems. Arduino IDE is used to write the firmware in C++ programming language.

5.1 Sensor Data Acquisition

The analog to digital converter (ADC) of the Arduino has a 10 bit analog to 0 to 1023 digital output with analog inputs of 0 to 5V. The resolution of the ADC is about 4.88mV/step. The analogRead() function obtains sensor readings with the right sampling duration to guarantee the precision of data.

5.2 ADC Conversion Formulas

The raw ADC values are converted to physical parameters using sensor calibration formulas derived from specifications:

$$Vbattery = (ADCvalue \times 5.0 \times 11.0) / 1023.0$$

5.3 Data Processing Algorithm

$$I = (ADCvalue \times 5.0 / 1023.0 - 2.5) / 0.185$$

$$T = (ADCvalue \times 5.0 \times 100.0) / 1023.0$$

To enhance the quality of measurements and decrease noise, a moving average filter is used. The algorithm has a circular buffer of the past 10 readings of each parameter and calculates the average value. The method is effective in filtering high frequency noise and the response time is reasonable.

The system also provides threshold based alarm generation. A system can cause visual alarms in the form of LED indicators to show when any parameter is out of predetermined safe values and can also invoke other safety mechanisms. Temperature limit is set to 45 °C and voltage limits are 10.5 V (minimum) and 12.6 V (maximum) and current limit is 5 A.

6. WORKING PRINCIPLE

The system is based on an endless cycle of data collection, processing, presentation, and communication. When the system is booted, it follows initialisation steps such as setting up of serial comms, LCD, WiFi module and sensor calibration.

Analog values are continuously read by the Arduino through voltage divider, ACS712 current sensor and LM35 temperature sensor. Every sensor datum is an average of several samples to enhance accuracy. The raw ADC values are transformed into the physical quantities with the help of the calibration formulas. The system digitally filters the readings to eliminate noise in measurements and compares the current readings with established safety limits.

The 16x2 LCD presents processed data in a rotating format, which means that voltage, current and temperature values are shown one after the other. The display is updated with a 2-second interval to give real time battery status information to the users. The system encodes sensor Data as HTTP GET requests and sends them to ThingSpeak platform through ESP8266 module at a regular time interval (15 seconds).

7. RESULTS AND DISCUSSION

The offered system was installed and tested in different working conditions to check its functioning, precision, and dependability. The breadboard based prototype system was tested using an 11.2V battery pack made of lithium ion as the test subject

7.1 Voltage Measurement Results

Figure 3: Voltage Data from ThingSpeak

The voltage sensor was also found to be consistent within the battery operating range. Comparison with reference measurements revealed an average error of less than 2 percent with the greatest deviation at the lower voltage range. The voltage divider circuit was stable and could be used in continuous monitoring..

7.2 Current Measurement Results

Figure 4: Current Data from ThingSpeak

The current sensor (ACS712) was found to be linear in the range of current measurements. The Hall effect sensing principle did not require series resistance, which reduces the amount of power to dissipate in the measurement path. The sensor was able to sense a charging and discharging current with the right polarity.

7.3 Temperature Measurement Results

Figure 5: Temperature Data from ThingSpeak

The LM35 temperature sensor had a very high degree of accuracy with low drift when used over a long period of time. The reaction to a change in temperature was less than 5 seconds, which is adequate when it comes to measuring battery thermal conditions. The sensor was able to identify the changes of temperature in charge cycles and load situations.

7.4 IoT Platform Performance

The ThingSpeak platform was able to successfully take in and show sensor measurements with very little latency. At steady WiFi conditions, data transmission reliability was above 95%. Web interface offered easy visualization of battery parameters and trending features of past data.

7.5 Performance Analysis

Parameter	Measured	Target	Status
Voltage Accuracy	98.2%	>95%	Pass
Current Accuracy	94.5%	>90%	Pass
Temperature Accuracy	97.8%	>95%	Pass
Display Response	<2s	<5s	Pass
Cloud Update	15s	15 30s	Pass
Transmission	96.3%	>95%	Pass

Table 2: System Performance Summary

The system showed a reaction period of less than 2 seconds to local display changes and around 15 seconds to send cloud information. The total accuracy of measurements was about 95%, which is sufficient to use the battery monitoring in practice.

8. ADVANTAGES AND APPLICATIONS

8.1 Key Advantages

Real time Monitoring: The system also offers real time, continuous monitoring of the key battery parameters, thus, allowing the detection of abnormal conditions immediately and proactive maintenance.
Remote Accessibility: IoT integration helps users to check the battery status regardless of their location as long as they have an internet connection, which is convenient and reassuring to EV owners.

Cost effectiveness: The system can be used in many applications with low cost components that are easily accessible and therefore can be widely adopted by a large population with low costs.
Scalability: The modular architecture can be easily expanded to add more parameters or more battery packs to the same system architecture.

8.2 Applications

The proposed system is used in several electric vehicle applications such as personal electric two wheelers, electric three wheelers, and small electric cars. In addition to the electric cars, the system can be modified to stationary energy storage systems, solar power installations, and backup power systems. This IoT connectivity allows connecting to smart grid apps to provide demand response and energy management in distributed power systems[9].

9. LIMITATIONS

Although the suggested system has proven to be effective in terms of battery monitoring, it should be admitted that there are several limitations:
Sensor Accuracy: Low cost sensors create measurement uncertainties in comparison to high precision laboratory equipment.. Although relatively cheap, voltage divider method can drift with time because of the tolerance of resistors and temperature variation.
Network Dependency: IoT operation needs a good internet connection. Cloud data transmission may be interrupted by network outages or a poor Wi Fi signal which prevents remote monitoring in locations with low connectivity.
Basic Charging Circuit: The charging circuit installed is a basic one without any advanced capabilities like cell balancing, temperature compensated charging or multiple charging profiles that are present in advanced battery management systems.

10. FUTURE SCOPE

The suggested system offers the basis of a number of improvements and additions that can expand its capabilities and applicability:
BMS Integration: With a full Battery Management System integration, it would be possible to have more advanced features such as cell balancing, state of charge estimation, state of health calculation, and predictive maintenance algorithms.
AI based Prediction: With the implementation of machine learning algorithms, predictive analytics of battery health can be implemented to estimate the remaining useful life and charge patterns based on usage history[10].
Mobile Application: It can be considered a mobile application with the development of a specific mobile application that would offer better user experience due to the use of push notifications and personalized alerts and detailed analytics available on smartphones. High-end Sensors: Addition of special sensors like INA219 to measure current and power accurately or coulomb counting devices to measure state of charge would be a better addition.
Measurement accuracy.

11. CONCLUSION

The paper has detailed an electric vehicle battery monitoring and management system based on IoT using Arduino UNO microcontroller, ESP8266 Wi Fi module, and different sensors. The suggested system is able to respond to the increasing demand of low-cost, high-quality battery monitoring systems in the rising electric vehicles market.

The introduced system shows efficient real time monitoring of such important battery parameters as voltage, current, and temperature. IoT technology integration allows remote accessibility using cloud based platforms allowing the user to easily access battery health information using any internet connected device.

The accuracy of the system is experimental validated to be around 95 percent and the response time is practical.

The system is affordable to implement with readily available components and thus it is accessible to be adopted by many applications especially those that are cost conscious like electric two wheelers and three wheelers.. The modular structure enables the extension and upgrading of this in the future to meet the future monitoring needs.

The capability of the system to give early warning of abnormal conditions helps in increasing the safety of EVs as it allows proactive response before critical failures set in. The work in the future will be aimed at including more sophisticated battery management, applying machine learning predictive analytics, and creating mobile applications with a better user experience.

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