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IoT-Based Electrical Vehicle's Energy Management and Monitoring System

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Abstract

It is necessary to move to the use of electric vehicles, as they represent the next generation of transportation. Electrical vehicle batteries may be damaged due to overcharging or over-discharging, so they need to precisely estimate the state of charge to extend their lifespan and protect the connected components they power. This paper presents battery management and monitoring system of electric vehicles, low-cost and IoT-based, in real-time, and easily used to help users through an application supporting the Internet of Things technology to display the essential information required about the battery's status as battery capacity and the charging and consuming current. This information is updated and displayed in real-time. The proposed system is implemented using an ESP32 microcontroller, blynk mobile application, and Blynk IoT platform.

Subject Areas

Wireless Communication, Computer Engineering

Keywords

State of Charge, Electrical Vehicle, IoT, Blynk

1. Introduction

Electric vehicles (EVs) are becoming more popular as gasoline prices climb. As a result of these circumstances, several automakers are looking into alternative fuel sources to gas. Electrical energy sources emit fewer pollutants; thus, they may benefit the environment. Furthermore, EVs provide tremendous energy-saving and environmental-preservation benefits. In most electric vehicles, lithium-ion batteries are used [1] [2]. The battery pack of an EV comprises cells of Lithium-Ion, to provide the needed voltage, these components are frequently assembled into modules and coupled in series. Lithium-Ion batteries are crucial devices, and their voltage and temperature must stay within a certain range to be safe. The cell may degenerate if the voltage or temperature goes below the set point. If these values surpass the maximum allowed, the cell may ignite. A normal Lithium-Ion cell's voltage and temperature must stay within [2.5; 4.2] V and [13; 60] C, respectively. This range of numbers is referred to as the cell's safety window [3].

Some factors affect the driving range, such as battery capacity, the engine's complexity, and the battery's age. Recent research was focused on increasing the driving range of electric vehicles (EVs), so that is led to requiring the development and enhancement of monitoring and management systems for batteries [4] [5]. The battery of an electric vehicle Management System (BMS) is a system that ensures the battery pack's safe functioning and reports its status to other systems. The BMS also estimates the State of Charge (SoC) of the Battery [3]. The State of Charge (SoC) of a battery is a crucial characteristic for increasing the battery's lifetime and providing information for the user to assess the battery's status when discharging or charging [6]. SoC is one of the most significant critical enablers for determining the current state of the battery so that it may be charged and discharged safely, extending its life [7] [8]. Also, the SoC represents the percentage of a battery's remaining charge capacity in terms of its maximum potential capacity.

The Battery's SoC functions similarly to a gasoline fuel gauge in a gasoline-powered automobile, indicating how much energy remains in the battery to power an EV. Correct battery SoC calculation aids in providing real-time information about the battery's capacity and energy and ensures a trustworthy and safe vehicle procedure. On the other hand, the SoC of batteries is difficult to determine since they are composite electrochemical devices with nonlinear performance that varies depending on internal and external inputs [9]. The batteries, particularly Li-ionised batteries, are located on the extremely high energy density axis, making them ideal for high energy density activities during the vehicle's driving cycle [10]. The coulomb counting method is simple and uncomplicated. In theory, coulomb counting requires monitoring the battery's current input and output to include and quantify charging. By integrating the current active across time, it calculates the total amount of battery power input or output. This results in a capacity that is usually measured in ampere-hours. The procedure may be used for all-electric vehicle battery types [11] [12].

The internet of things (IoT) is an exciting research topic in today's world. Every electronic device around us may be connected to each other to establish communications in the Internet of Things, which is currently developing and widely utilized [13] [14]. Also, the IoT is the interconnection of physical devices and other embedded electronics, sensors, actuators, and network connections that allows these items to gather and share data [15] [16]. Physical equipment can be linked to the virtual world and accessed from anywhere, while IoT devices and items are always linked to the real world. Thanks to their remote operation capabilities, IoT devices are now used for a wide range of real-time applications, including innovative media, environmental monitoring, smart manufacturing, intelligent medical and healthcare, smart buildings, home automation, energy management, transportation, and so on [17] [18]. Several IoT devices on the market are utilized for the mentioned purposes. The application and the work at hand determine the IoT device used. However, Arduino and Raspberry Pi are the most widely used IoT devices because of their ease of use and operation [19] [20] [21].

2. Battery Management and Monitoring System Block Diagram

The proposed system is shown in **Figure 1** designed for EV users based on IoT. the implemented system can be realized in the mobile application that allows to monitors and management whole system, which allows users to monitor EV battery status (SoC), input current, output current, in addition, it gives a summary of total charging current also it manages the charging operation. All these parameters are updated and displayed in real-time. The proposed system is composed of the following parts, a microcontroller ESP32 with built-in Wi-Fi, two Current sensors, Li-Ion Battery, a Li-Ion battery fuel gauge sensor, and Li-Ion Battery Charger. Also, the total charging current's summary after each charging operation is received as a message through a mobile telegram application.

The biggest reason why select ESP32 is that it has built-in Wi-Fi and Bluetooth. So there is no need for additional radio modules like on most Arduino boards. The ESP32 is just one chip, with everything in 1 package.

The system operates by connecting two current sensors and a Li-Ion battery fuel gauge sensor to ESP32; the information received from sensors is collected and processed by ESP32 and uploaded to Blynk Server through the Wi-Fi module bulletin ESP32. All information is displayed and updated in real-time, and the charging operation is managed through the blynk android mobile application.

3. Battery Management and Monitoring System Prototype

The architecture of the implementation of the battery management and monitoring system of the electric vehicle based on IoT is explained in **Figure 2**. It has been implemented using the microcontroller ESP32 in this prototype system PC USB port is used as a power supply source or any sources with 5 V dc needed to turn on the system. Use the user's mobile phone's 3G connection as an internet source to upload data from the esp32 to the Blynk server IoT platform. To establish internet connection, use the built-in Wi-Fi module on the ESP32. It combined two current sensors to ESP32, one to read current into the battery and another to red current out from the battery. A Li-Ion battery fuel gauge sensor is used to get the battery capacity, or SoC (state of charge), also connected Li-Ion Battery Charger to charge the battery and uses a relay to manage charge operation.

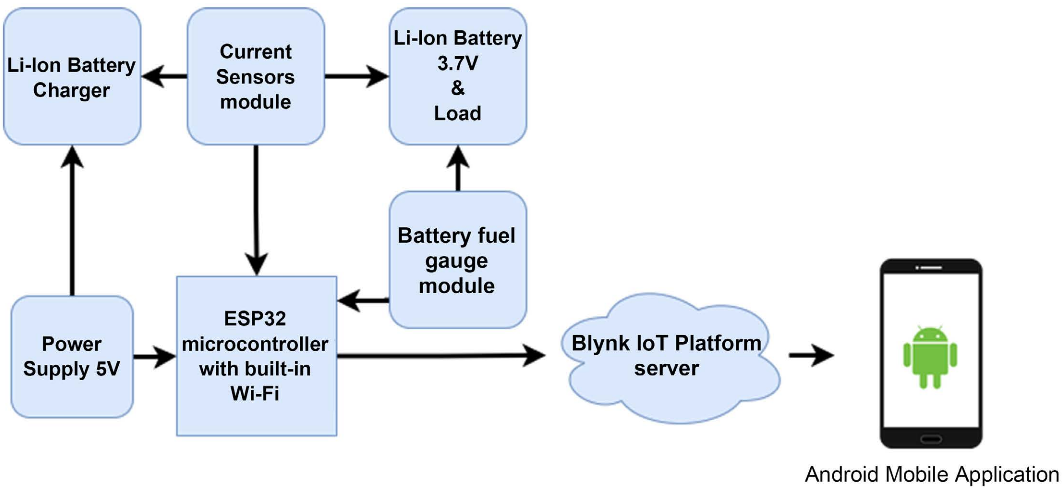


Figure 1. Block diagram of the battery management and monitoring system.

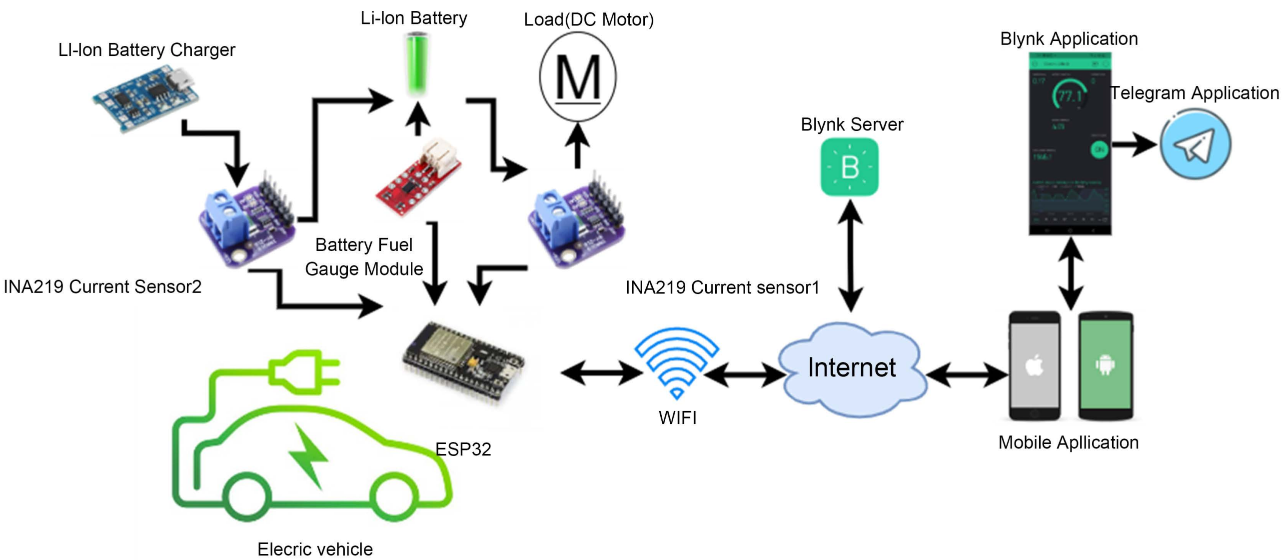


Figure 2. Battery management and monitoring system of the electric vehicle architecture.

The system notifies the user to necessary charge the battery when the Battery SoC becomes 30% through Blynk mobile application, as shown in Figure 3, to protect the battery from over-discharge damage and increase its life. The charging operation ends either by pressing the off button or when the battery is full. The Li-Ion Battery Charger stops the charging process using a protected circuit built into it.

4. Battery Monitoring and Management System Scenario

Using ESP32 to collect data from the sensor and process it, using i2c protocol to connect two current sensors and battery fuel gauge module to the same serial port. SDA and SCL data transfer merely utilizes two bi-directional open-drain lines. Both of these lines are cranked up. Serial Data (SDA) is used to transfer data, while a serial Clock (SCL) carries the clock signal. Each clock's high to low

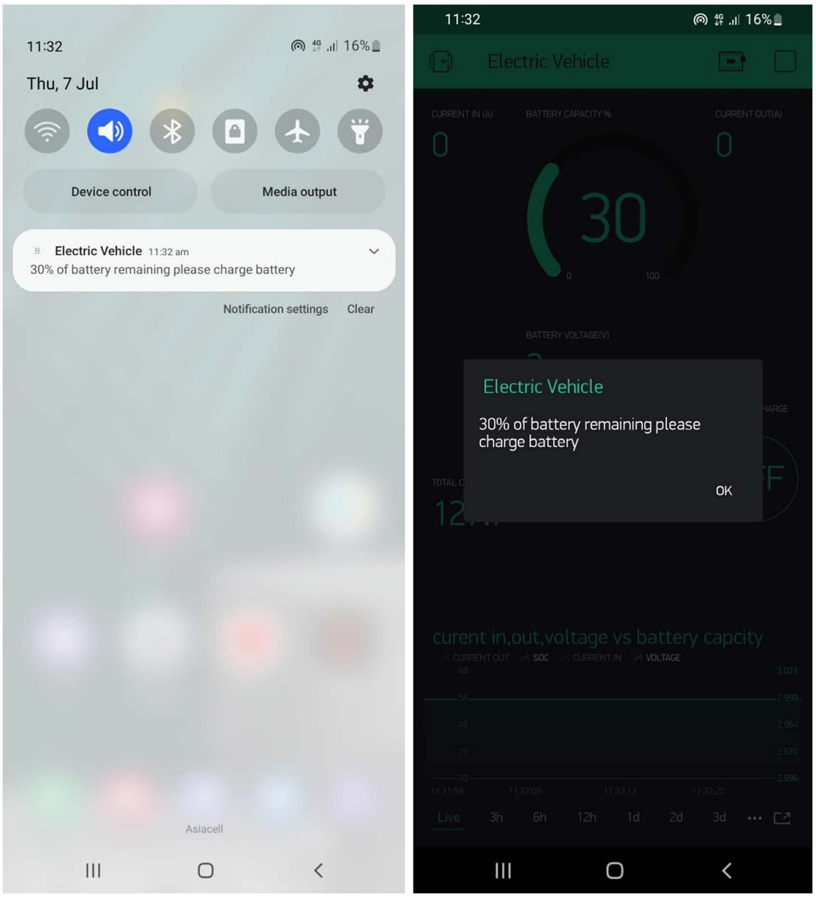


Figure 3. The proposed system warning low battery remaining.

pulse on the SCL line synchronizes each data bit transferred on the SDA line. Current in/out value received from INA219 by ESP32 and battery SoC obtained from MAX 17043. The relay connected between Battery and TP4054 to manage to charge operation. To send data from ESP32 to the BLYNK IoT platform server, there must be an internet connection and account on the BLYNK IoT platform. Use Wi-Fi built-in ESP32 to connect to the router, establishing an internet connection. To ensure a secure connection when transferring data between the ESP32 and BLYNK server unique authentication token is used that is defined when registering an account on BLYNK mobile application. The data received from the BLYNK server was shown on a digital dashboard using gadgets using the mobile application.

4.1. ESP32 Microcontroller

As shown in Figure 4(a), the ESP32 is an effective SoC microcontroller with built-in Wi-Fi 802.11 b/g/n, dual-mode Bluetooth 4.2, as well as peripherals. It is a superior successor to the 8266 chip, mainly because it includes two cores clocked at different speeds up to 240 MHz. Aside from these improvements, the GPIO pins' number has been raised from 17 to 36, and 4 MB of flash memory has been added.

(a) (b) (c) (d) (e)

Figure 4. Show hard ware element: (a) Microcontroller ESP32, (b) INA219 current sensor, (c) Relay, (d) TP 4056 Li-Ion Battery Charging Board and (e) battery fuel gauge module MAX 17043.

ESP32 comprises two primary parts (Xtensa LX6 processor made with 40 nm technology). Individual CPU cores can be controlled. A total of 520 KB of on-chip SRAM is available for data and instructions. The ESP32-Grover, for example, has 4 MB of external SPI flash and 8 MB of SPI PSRAM (Pseudo static RAM). Depending on the board type [22] [23].

4.2. INA219 DC Current Sensor

The INA219 sensor is used to determine the current flow. The INA219 is a current shunt and power meter with an I2C or SMBus compliant interface, as seen in **Figure 4(b)**. It provides precision-controlled systems with digital voltage, current, and power data for precise decision-making. Flexible design for measurement resolution and continuous versus triggered operation is feasible with programmable registers. The gadget monitors shunt voltage drop and bus supply voltage with customizable conversion filtering and times. A customizable calibration value and an integrated multiplier can detect direct readouts of current in amperes. Power is calculated in watts using a different multiplication register. Sixteen programmable addresses are available on the I2C or SMBUS compliant interface. There are two classes of the INA219: A and B. On buses with the voltages ranging from 0 to 26 V, the INA219 detects shunts. From a single 3- to 5.5-V supply, the gadget can take up to 1 mA of supply current. The INA219 has a temperature range of −40˚C to 125˚C. The Simplified Schematic is explained in **Figure 5** [24].

Figure 5 shows a pin-out schematic for the breakout board. Vcc, Gnd, Scl, Sda, Vin, and Vin+ are the pin-outs from left to right, Vcc and Gnd provide power to the breakout board, Scl and Soda provide I2C clock synchronization and data transfer, and Vin and Vin+ provide power to the DUT (Device Under Test) via the INA219's sense resistor, remembering to connect Vin to the high-side of the voltage supply and Vin+ to the high-side of the voltage supply [25].

4.3. Charge-Discharge Management Relay

The charging operation is managed using Relays. Relays are electromechanical or electronic switches that open and shut circuits shown in **Figure 4(c)**. Relays open and close connections separated electrically between two circuits and joined them smoothly. When a relay contact is normally open (NO), as shown in

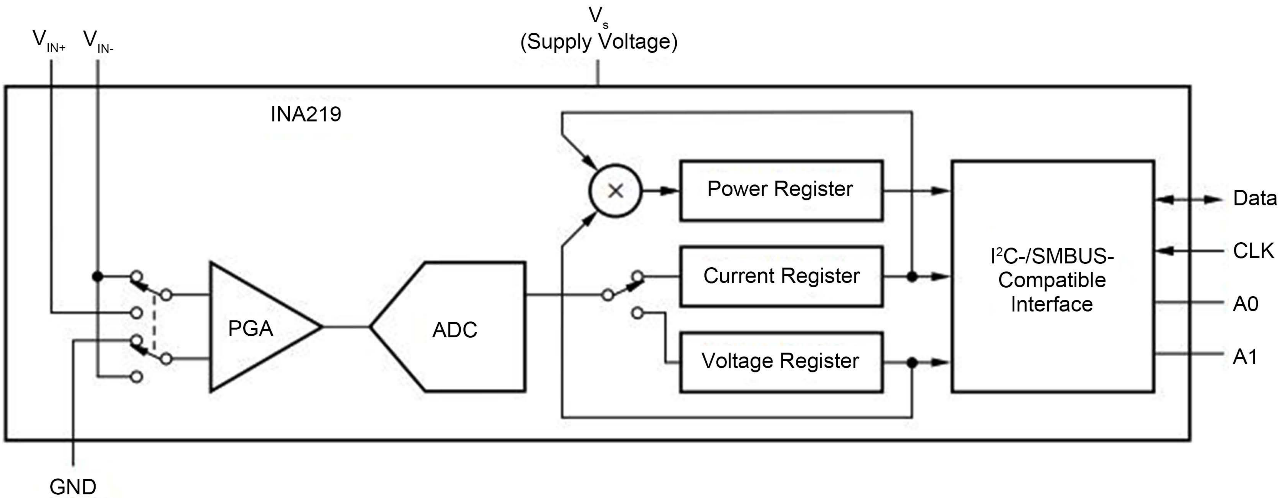


Figure 5. Simplified schematic of INA219.

relay schematics, there is an open contact when the relay is not actuated. The connection is closed when a relay contact is Normally Closed (NC), even if the relay is not activated. Applying electrical current to the contacts will change the state in either situation. Except for tiny motors and low-ampere Solenoids, relays are primarily employed to switch lower currents in a control circuit and do not manage power-consuming devices.

Relays may "control" bigger voltages and amperes because a tiny voltage given to a relay's coil can cause the contacts to switch a high voltage. Protective relays can avoid equipment damage by detecting electrical anomalies such as overcurrent, undercurrent, overloads, and reverse currents. Starting coils, heating elements, pilot lights, and audible alerts are all controlled by relays [26].

4.4. TP 4056 Li-Ion Battery Charging Board

A TP4056 1A Li-Ion Battery Charging Board has Micro USB, it is a tiny module with current protection shown in **Figure 4(d)**. It is ideal for charging a single cell of 3.7 V, 1 Ah or greater lithium-ion (Li-Ion) batteries without their protection circuit, such as 16550s. This module will give a 1 A charge current, when the charge is complete it is switching off, thanks to the TP4056 charger IC and the DW01 battery protection IC. Also, consider the case where the battery voltage falls below 2.4 V. The safety IC will then turn off the load to keep the cell from running at too low a voltage, as well as protect against over-voltage and reverse polarity connections (it will usually destroy itself instead of the battery).

Additional features include a current meter, under-voltage lockout, automated recharging, and two status pins to presence of an input voltage and signify charge termination and the [27].

4.5. Li-Lon Battery Fuel Gauge Module MAX 17043

The MAX17043/MAX17044 shown in **Figure 4(e)** are the host-side fuel-gauge systems for lithium-ion (Li+) batteries in handheld and portable devices that are ultra-compact and low-cost. The MAX17043 is set up to work with one lithium cell, whereas the MAX17044 is set up to work with a two cell pack. The MAX17043/ MAX17044 employ Model-Gauge, a sophisticated Li+ battery-modelling system, to continually track the battery's relative SoC through a broad range of charge/ discharge profiles. Unlike standard gasoline gauges, the Model-Gauge algorithm does not require battery relearn cycles or an additional current-sense resistor. With minimum contact between micro coulombs and the device, temperature correction is achievable in the application. Inegrated circuit can be placed on the system side, decreasing the battery's cost and sourcing limitations. An I2C interface is used to access data sets for measurement and capacity estimation.

The model accurately replicates the internal dynamics of a Li+ battery and calculates the state of charge. The model considers the battery's time effects generated by chemical reactions and impedance. The SoC calculation for MAX17043/ MAX17044 does not acquire errors over time. Compared with typical coulomb counters, which suffer from SoC drift due to current-sense offset and cell self-discharge, this is a benefit. This model performs well for various Li+ chemistry variations at multiple temperatures and ages. The MAX17043/MAX17044 must be configured with application-specific configuration data to ensure optimal performance.

4.6. IoT Based Battery Management and Monitoring System

Blynk is the most user-friendly IoT platform, with an application builder that runs on iOS and Android. In addition, it has a collection of libraries that allow you to create incredible IoT applications in minutes using any chosen hardware platform. It allows to easily create interfaces for controlling and monitoring hardware projects from iOS or Android devices by simply dragging and dropping widgets [28] [29]. A digital dashboard is a graphical user interface (GUI) formed. Widgets can be dragged and dropped from the widget box. Every widget to uses some form of points to function. A user will get 2000 energy (points) when establishing a Blynk account. When a widget is utilized, the energy balance decreases [30] [31]. Blynk mobile application allows users to watch the electric vehicle battery capacity, current input/output battery currents consumed by the load, and manage the charging operation (start and stop) through a button on the digital application dashboard. After the battery charging process is complete, a message will be sent to the Telegram application containing the total amount of current used in the charging operation.

Design of Battery Management and Monitoring System Circuit

The prototype of the battery management system is shown in **Figure 6**. And the circuit connection design is shown in **Figure 7**. Because INA 219 and MAX17043 use the Inter-Integrated Circuit (I2C) Protocol, which enables one or more "controller" chips to communicate with a large number of "peripheral" digital integrated circuits ("chips"), so can connect to the same serial port on the ESP32 microcontroller. Through soldering (A0, A1) as programmable addresses to select

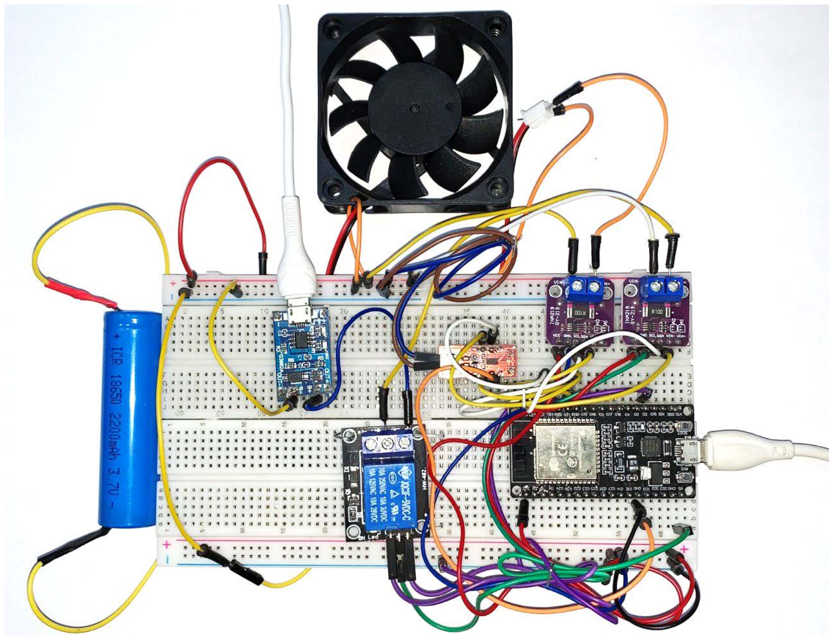


Figure 6. Prototype of battery management and monitoring system.

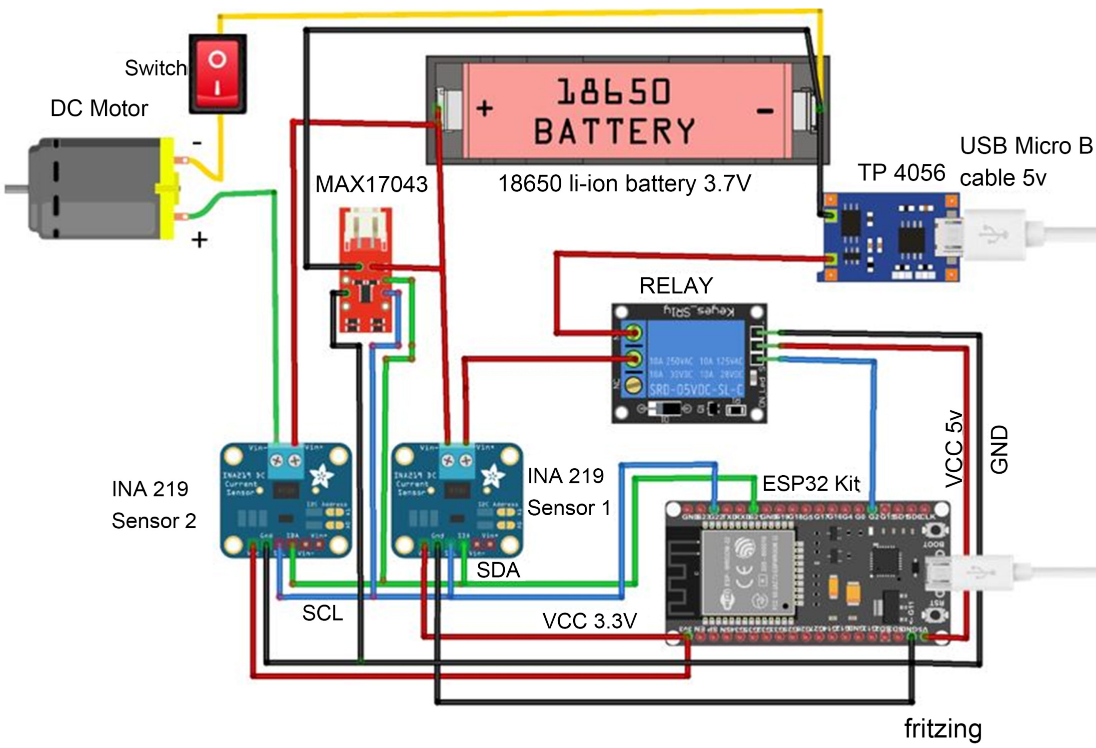


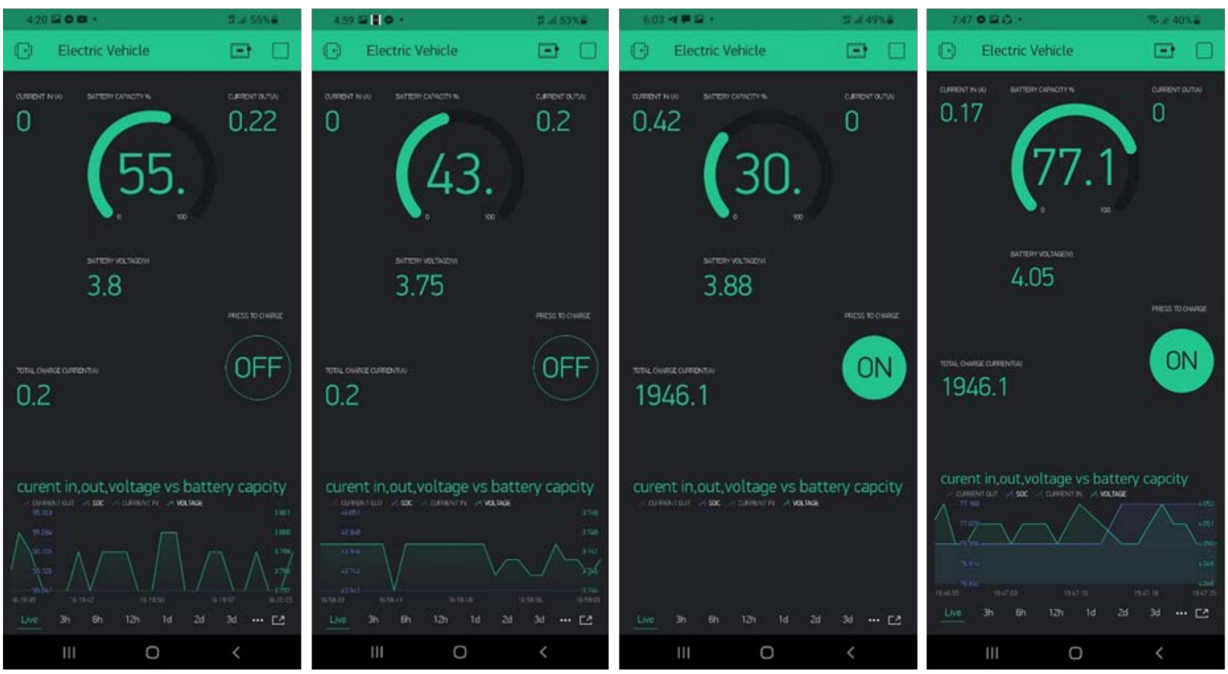
Figure 7. Proposed system circuit design.

between two INA219. There are connected Serial Clock Line (SCL) and SDA (Serial Data Line) pins from two sensors, and MAX17043 is linked to D22 and D21. VCC and GND connected from two INA219 to 3.3 v and GND pin of ESP32 to supply the sensor with needed power. MAX17043 joined as (+, −) pins connected to (+, −) battery terminal to return the battery capacity as well as (GND) pin connected to (GND) pin in ESP32. The relay used in the circuit to control the charging operation uses a normally open pin, controlled through the application. When the user presses the application dashboard, the button (press to charge) changes from off to on; it is also used to start charging. When the press button (press to charge) changes from on to off, the charging stops.

5. Result and Discussion

A prototype system has been designed, implemented, and tested after connecting all components, as shown in Figure 6. The system is powered from a pc USB port and connected the ESP32 to the router using an ESP32 built-in Wi-Fi module. All Ev's data are collected and processed using ESP32, transmitted to the Blynk server and displayed by the blynk mobile application; all information is updated and displayed in real-time. The mobile application dashboard view by the user is shown in Figure 8(a), Figure 8(b) and Figure 8(c), Figure 8(d) for the charging/discharging process respectively.

The 18650 Li-Ion battery is fully charged using TP4056 Li-Ion battery charger and then starts system testing. The mobile application is used to display information about the status of the battery, like capacity or SoC, charging/discharging current, and battery voltage. In addition, a chart gadget that describes the relationship between them. The total charging current is displayed every time press button (press to charge) ON, OFF, and then the exact number is sent to the user's telegram application. When the load is turned on, the discharge operation starts; through this operation, the capacity of the battery decrease as well as the voltage, as shown in Figure 9. To start the charging procedure, the load must be turned off. The charging process does not begin unless press the (press to



(a) (b) (c) (d)

(e)

Figure 8. Shows application dashboard: (a) and (b) discharge operation, (c) and (d) charge operation and (e) massage received by telegram application.

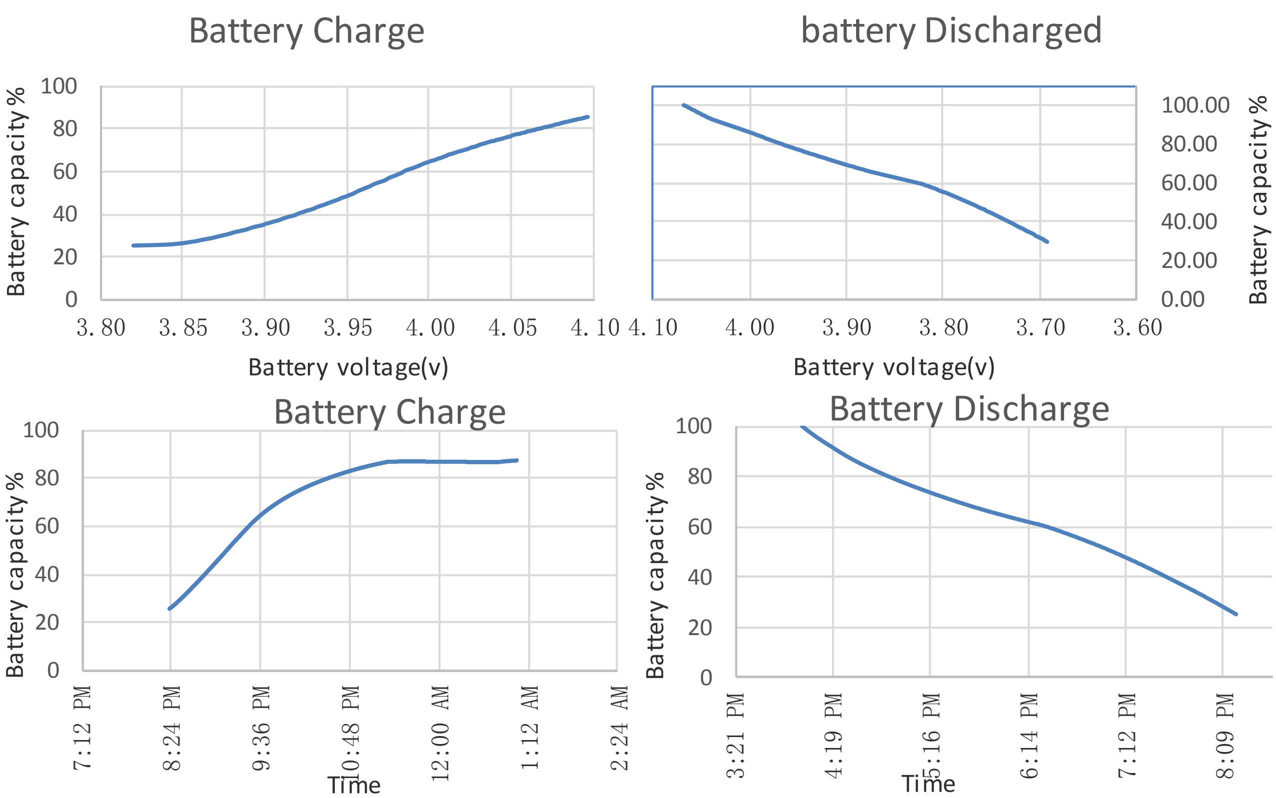


Figure 9. Battery charge and discharge with the voltage and time profile.

charge) button to close the relay and start charging the battery. During this operation, the capacity of the battery and voltage increase, as shown in **Figure 8**. The charging process stops in one of the two cases, either when pressing on the (press to charge) button or when the battery is fully charged through the TP4056 board protection circuit. Each time press (ON, OFF) press to charge button, a message is sent to the user's Telegram app containing a summary of the amount of current the battery was charged with. After each charging process, this feature can be used as a bill and kept as a booking to know the charging date within a specified period. The message sent to the telegram is shown in **Figure 8(e)**. The time taken for the charging and discharging process is illustrated in **Figure 7** with an average charging current (0.24 AH) and average discharging current (0.195 AH).

6. Conclusions

This paper introduces a prototype of the electric vehicle's battery management and monitoring system based on IoT, Using two current sensors INA219 to measure current in/out from battery and battery fuel gauge module MAX17043 for SoC calculation, they are connected to ESP32 microcontroller can use IoT capability through connecting the ESP32 to the internet, this allow users to manage battery charge/discharge; as well as monitoring the battery SoC status by displaying all information on the mobile application dashboard and updated in real-time. Also, the suggested management system allows the user to detect any upnormal current consumption through the current out widget on the application dashboard. That led to extending battery life by protecting it from overcharge and over-discharge.

The method used to calculate battery SoC advantageous compared to traditional the classical coulomb-counter-based fuel gauges suffers from accuracy drift due to the in the current-sense measurement, there is an offset error. Although the inaccuracy in such systems is frequently little, it grows over time, cannot be eliminated, and necessitates periodic corrections. Corrections are typically made at a predetermined SoC level, which is usually near full or empty. Other systems modify the voltage of the battery when it is relaxed. After an extended period of inactivity, these systems calculate the accurate SoC depending on the battery voltage. Both share the same limitation: the error in the system is limitless if the correction condition is not observed over time in the actual application.

In some cases, a full charge/discharge cycle is required to eradicate the drift inaccuracy. To establish the factual correctness of a fuel gauge as experienced by end-users, the battery should be dynamically exercised. The end-user accuracy cannot be grasped with simply simple cycles. Because they do not rely on current information, MAX17043/MAX17044 does not suffer from drift.

Conflicts of Interest

The authors declare no conflicts of interest.

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