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Development of an IoT-Integrated Battery Management System for Enhanced Safety and Efficiency in Electric Vehicles

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A B S T R A C T

Electric vehicles (EVs) have gained prominence as a sustainable alternative to traditional vehicles, primarily due to their reduced greenhouse gas emissions. These vehicles rely on rechargeable batteries, which often require prolonged charging times, leading to the introduction of battery swapping stations. Here, vehicle owners can quickly exchange their depleted batteries for fully charged ones. However, this system raises concerns about battery security and maintenance, especially when charging and discharging occur without the owner's supervision. This work aims to develop an Internet of Things (IoT) based Battery Management System (BMS) to address these concerns. Utilizing the ATMEGA328P controller, the system monitors, and controls various battery parameters, including charging and discharging currents, operating temperature, and cut-off voltage. Additionally, it integrates a GPS module to provide real-time battery location updates. A dedicated mobile application offers users real-time monitoring capabilities. The system not only ensures the battery's protection and longevity but also offers peace of mind to EV owners. The work's broader implications include promoting responsible energy consumption, fostering smart communities, and potentially serving as a revenue source for academic institutions and the electronics industry.

Keywords: Electric Vehicles (EVs), Battery Management System (BMS), Internet of Things (IoT), Battery Swapping Stations, Real-time Monitoring

1. Introduction

In the face of escalating global concerns about climate change, there has been a pronounced shift towards sustainable energy solutions. This transition is evident across nations, with countries like Zimbabwe leading the charge in advocating for green energy. The primary motivation behind this advocacy is the minimal environmental impact associated with sustainable energy. Zimbabwe's commitment to this cause is enshrined in its 2013 Constitution, specifically Section 73. This section guarantees every citizen an environment that promotes health and well-being. Furthermore, it mandates the protection of the environment for both the present and future generations, emphasizing the need to reduce pollution and champion ecological conservation. As a result of this commitment, several industries in Zimbabwe have made the switch to green energy, marking a significant stride in reducing the emission of harmful gases.

2. Background

Over the past decade, the transportation sector has witnessed a transformative change with the advent of electric vehicles (EVs). These vehicles have emerged as a potent solution to the environmental challenges traditionally associated with road transport. Their ability to significantly reduce greenhouse gas and pollutant emissions, in comparison to gasoline and diesel vehicles, has gained them widespread recognition (Tintelecan et al., 2019). This global sentiment was further solidified at the Cop26 summit in 2022. During this summit, U.S. President Joe Biden showcased his support for EVs by allocating a substantial 5 billion dollars for the development of EV charging infrastructure.

At the core of EVs are their rechargeable batteries, which serve as the primary energy source (Pipitone et al., 2021). These batteries, akin to fuel in traditional vehicles, require periodic recharging. However, a significant challenge associated with these batteries is the extended duration required for charging, often stretching to an hour. This prolonged charging time, coupled with the high costs of the batteries, poses a challenge for potential EV adopters.

To address the challenge of extended charging durations, the concept of battery swapping stations has been introduced. These stations function similarly to traditional fuel stations but cater to EVs. Instead of refueling, consumers can quickly exchange their depleted batteries for fully charged ones. This innovative approach, often termed as "battery-as-a-service," ensures minimal downtime for EV users. However, this system's efficiency necessitates a robust monitoring mechanism, emphasizing the importance of a comprehensive Battery Management System (BMS) for EVs.

3. System Architecture and Description

The design of the system was deeply rooted in the prototyping methodology, a concept championed by Doke and Swanson in 1995. This methodology was a multi-step process that began with the identification of initial requirements, where the primary project goal was defined. Following this, potential system designs were proposed, with the most effective one selected based on the conceptual framework. A preliminary system mock-up was then developed, which underwent a rigorous evaluation by stakeholders. Their feedback was invaluable, guiding the subsequent review and redesign phases. Once stakeholders were satisfied with the revised prototype, the actual system development commenced. The system was web-hosted, ensuring universal access via HTTP, with Firebase serving as its primary database. The system, as visualized in the Block Diagram (Fig. 1), was a closed-loop design.

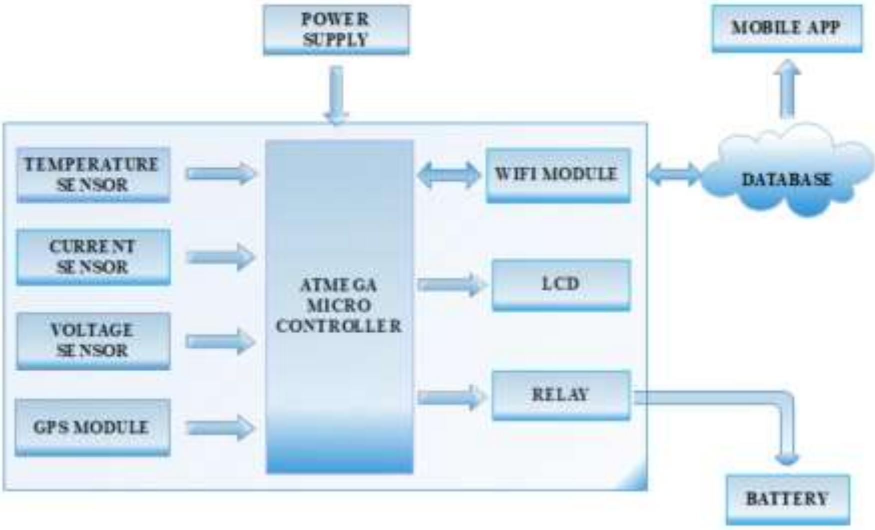


Fig. 1 Block Diagram

It seamlessly integrated various components, each serving a distinct purpose, be it for input, processing, or output. Power supply, numerous sensors, a controller (specifically the ATMEGA328P), and output interfaces were some of the system's pivotal components. The overarching aim of this project was to design a comprehensive Battery Management System (BMS) tailored for charging stations and Electric Vehicles (EVs). This system was a confluence of modern technologies, integrating the Internet of Things (IoT), an array of sensors, Wi-Fi modules, and a user-friendly mobile application. The System Flow Chart for Charging Parameters (Fig. 2) offered a visual representation of this.

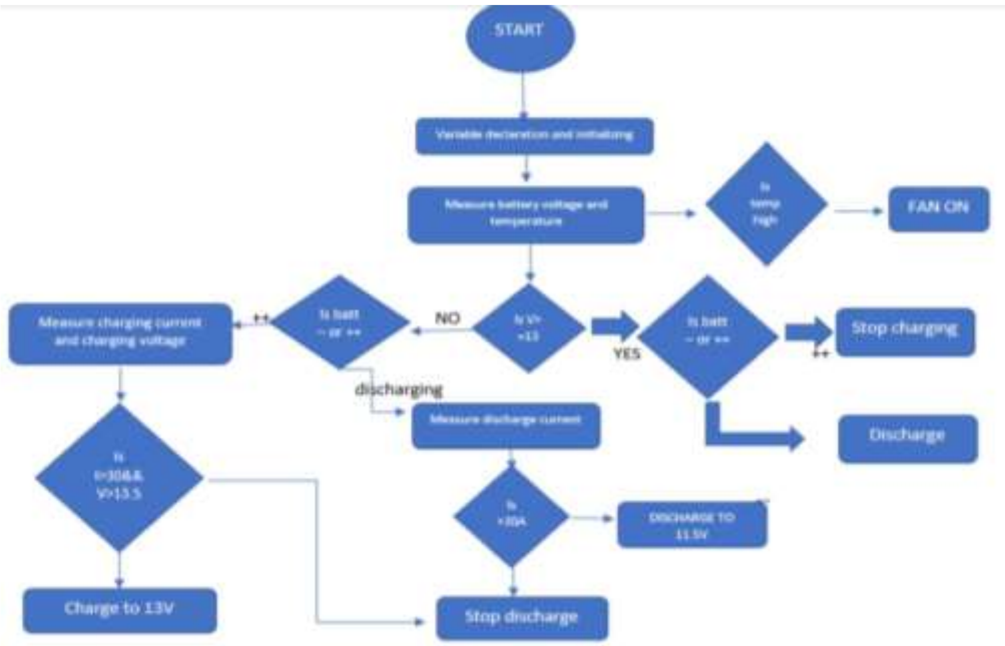


Fig. 2 System Flow Chart

4. Hardware and Software Implementation

The system's design was a harmonious blend of hardware and software elements. While the hardware aspect was visualized through a functional block diagram, the software segment was brought to life using the Arduino IDE, a platform known for its flexibility and efficiency in microcontroller programming. The Arduino IDE was the cornerstone of the system's software development. It was enriched with many libraries, each tailored for the ATMEGA328P, ensuring application development was both efficient and streamlined. Tools like the code Explorer and real-time debugging further enhanced the programming experience. The hardware development phase was a thorough process. It began with the crafting of the circuit design and PCB layout using the Proteus software, as depicted in the Proteus Schematic (Fig. 3).

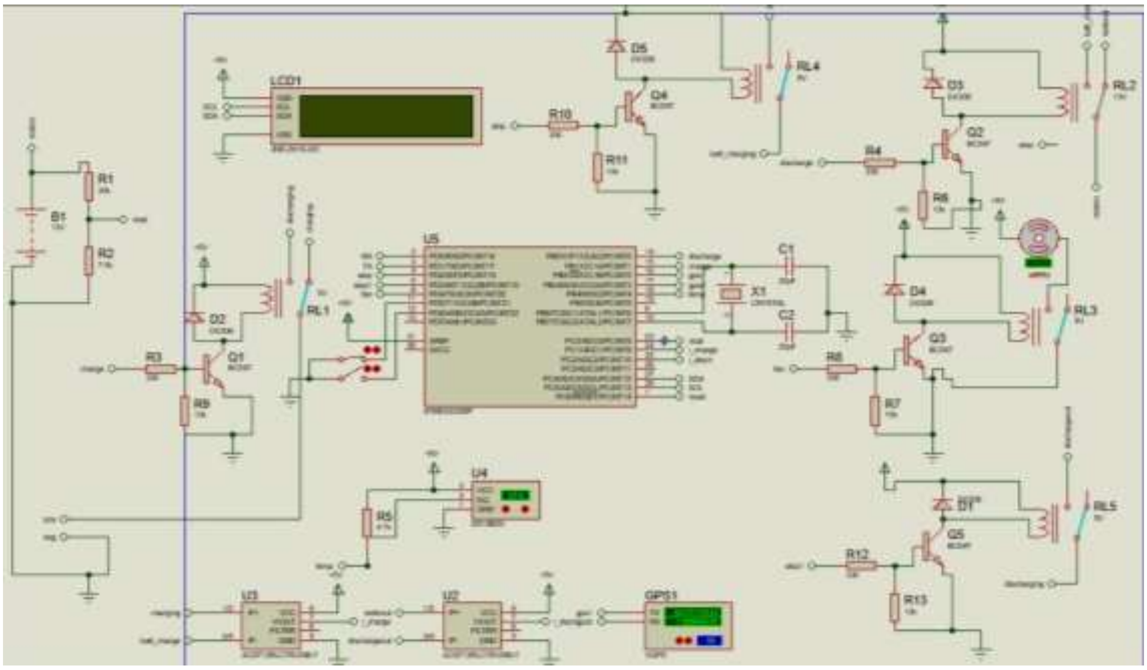
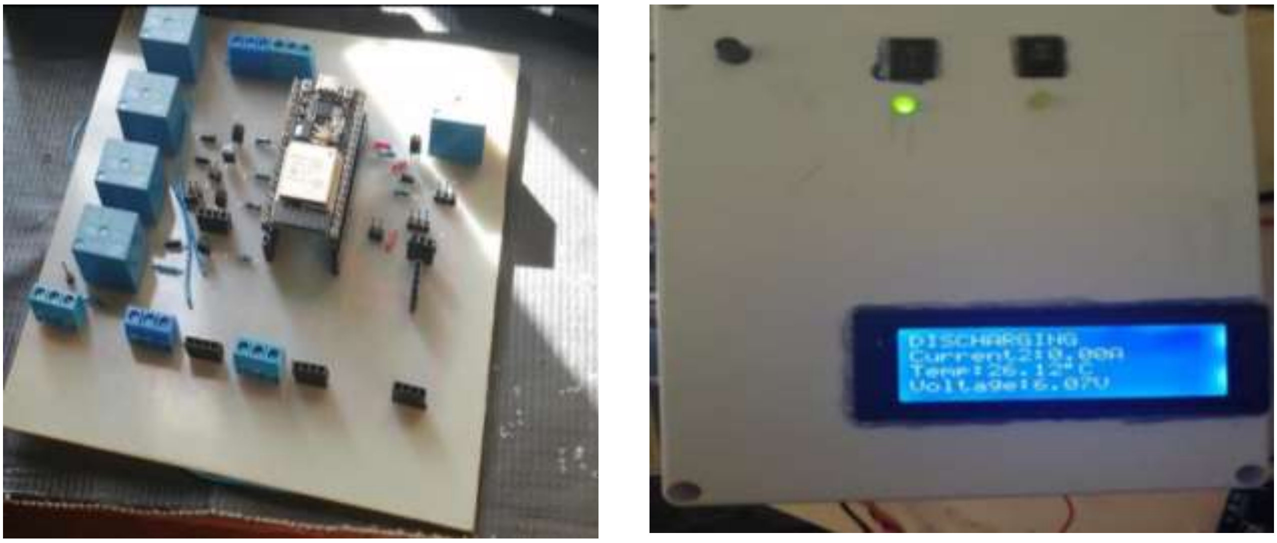


Fig. 3 Proteus Schematic

Once the Proteus simulation was validated, the PCB layouts were generated. This was followed by a series of steps, including etching, where the PCB layout was printed on transfer paper and ironed onto the PCB; drilling, where precise holes were made on the PCB using a 1mm drill bit; and component population, where components were carefully soldered onto the PCB (Fig. 4a). The final product was then encased for protection, as shown in the System Casing (Fig. 4b).



a) Soldered Components b) System Casing

Fig. 4 a) Soldered Components b) System Casing

5. Results

After we finished putting together the hardware and software, we tested the prototype to make sure it did what we wanted. We made a Battery Management System and an Android app to give all the alerts and messages. The app told users about the charging voltage, charging current, and battery temperature. The data from the system went to the app, showing things like where the battery was and how it was charging or discharging. We had some trouble updating this data in real-time, so we used Firebase, a real-time database. The Android app did its job by showing the charging details. You can see this in Fig. 5, which shows location updates, Fig. 6, which shows the app's parameters, and Fig. 7, which is the main page of the app.

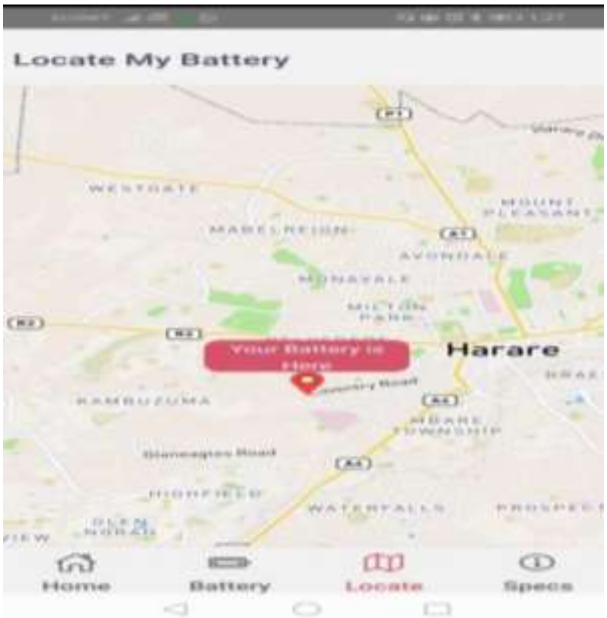


Fig. 5 Location Updates

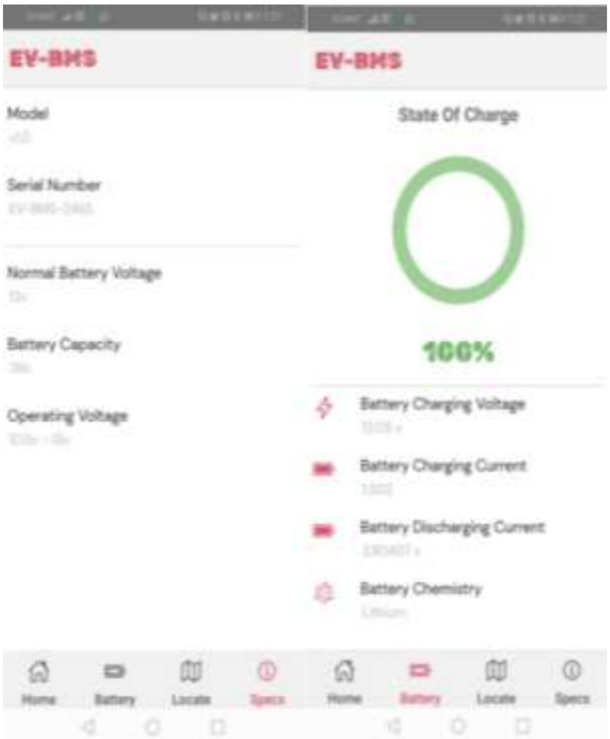


Fig. 6 Mobile Application Showing Parameters

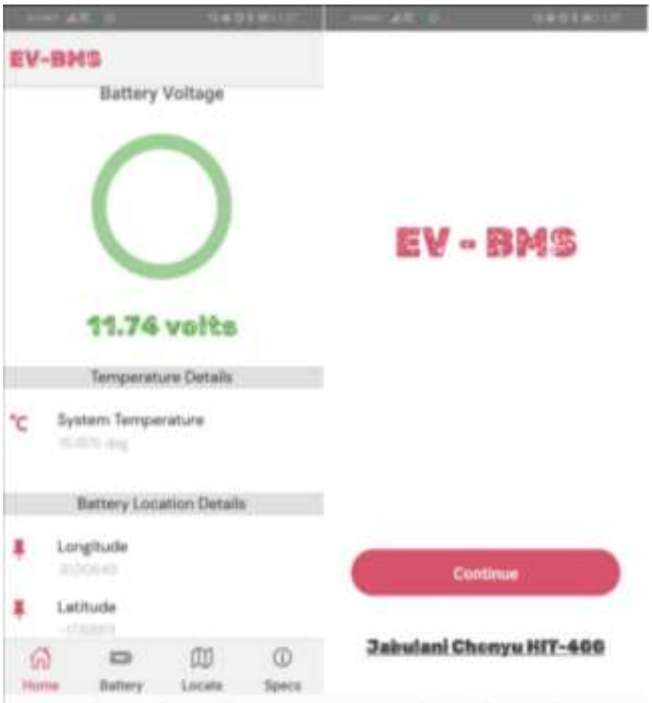


Fig. 7 Mobile Application First

We also looked at how the system worked when charging and discharging. For charging, if the charging current was 2A or less and the battery charging voltage was 13.25V or less, the battery charged and showed its location. But if the charging current was more than 2A or the battery charging voltage was more than 13.25V, the battery stopped charging. This was shown by both yellow and green lights turning on. Also, if the temperature went above 30°C, the battery stopped discharging, shown by the two lights again.

For discharging, if the battery wasn't charging or discharging, the system checked the battery's temperature and voltage. The GPS always updated where the battery was as long as the system was on. We had some rules for discharging too, like the discharge current had to be 4A or less, and the battery voltage had to be more than 11.5V. If these rules were followed, the battery discharged well, giving the needed voltage, shown by the green light. But if these rules weren't followed, the battery would stop discharging, and both the yellow and green lights turned on. Looking back at the goals, the project did what we wanted. It checked and controlled how the battery charged and discharged and sent this info to the mobile app in real-time.

6. Conclusion

The transition towards sustainable energy solutions, particularly in the transportation sector, is of paramount importance in today's climate-conscious era. This paper delved into the intricacies of developing a comprehensive Battery Management System (BMS) tailored for Electric Vehicles (EVs) in conjunction with battery swapping stations. The innovative approach of battery swapping, coupled with the real-time monitoring capabilities of the BMS, offers a promising solution to the challenges traditionally associated with EV battery charging durations. Through the integration of modern technologies such as the Internet of Things (IoT), GPS modules, and dedicated mobile applications, the system ensures efficient battery management, real-time data updates, and enhanced user experience.

The project's success in controlling and managing the battery, especially in linking the control system with the database and the mobile application, marks a significant advancement in the world of EV battery management. Moreover, the use of specific sensors, controllers, and software tools ensured the system's precision and reliability. While the project achieved its primary objectives, the recommendations for future work, such as the integration of ESP32 and the visualization of charging stations on maps, pave the way for further enhancements and refinements.

In conclusion, the development and implementation of an IoT-based BMS for EVs not only address the immediate challenges faced by EV users but also contribute to the broader goals of promoting sustainable energy consumption, reducing greenhouse gas emissions, and fostering a greener future. The insights and findings from this study hold significant potential for academic researchers, industry professionals, and policymakers alike, as the world continues its journey towards a more sustainable and eco-friendly transportation landscape.

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