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Design and Implementation of an IoT-Based Charger Monitoring and EV Fire Protection System

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ABSTRACT: The increasing use of battery charging systems in electric vehicles (EVs) and associated applications has raised serious concerns about overheating, fire hazards, and insufficient real-time supervision. This paper presents the design and implementation of an IoT-based charger monitoring and EV fire protection system aimed at improving safety and enabling real-time remote supervision of battery charging processes. The system employs an Arduino Uno microcontroller as the central processing unit, supported by an ESP32/NodeMCU module for Wi-Fi-enabled cloud connectivity.

An LM35 temperature sensor continuously measures the thermal state of the charger and battery, while an MQ-2 smoke and gas sensor and a flame sensor provide multi-layered fire detection. A voltage and current sensing module monitors electrical anomalies in real time. When any parameter exceeds its predefined safe threshold, the system triggers an automatic relay-based cut-off to isolate the charger, activates a buzzer alarm and LED visual indicators, and transmits an instant alert to the user via the Blynk IoT platform.

A cooling mechanism using a DC motor and Peltier module provides active thermal management. The proposed system demonstrates significant improvements in battery charging safety by combining multi-sensor monitoring, automated protection responses, and cloud-based IoT communication, substantially reducing the risk of fire accidents and equipment damage.

Experimental results confirm reliable detection of fault conditions with response latencies well within acceptable bounds, validating the suitability of the proposed platform for real-world EV charging safety applications.

KEYWORDS: IoT, EV Fire Protection, Charger Monitoring, Arduino Uno, ESP32, Blynk, LM35 Sensor, MQ-2 Sensor, Relay Module, Temperature Sensor, Cloud Monitoring

I. INTRODUCTION

With the rapid proliferation of electric vehicles (EVs) and battery-powered electronic devices, the safe management of battery charging processes has become a critical area of concern. Batteries, particularly lead-acid and lithium-ion types commonly used in EVs, are prone to overheating, overcharging, and thermal runaway when operated without adequate monitoring and protection. These conditions can lead to catastrophic outcomes including fires and explosions, posing significant safety risks to infrastructure and personnel.

The emergence of the Internet of Things (IoT) has created transformative possibilities for remote monitoring and intelligent automation of safety-critical systems. By integrating microcontrollers with cloud platforms, real-time sensor data can be aggregated, processed, and acted upon instantaneously, regardless of the physical location of the user. This capability is especially valuable in EV charging environments, where thermal events may develop rapidly and require immediate intervention.

Existing battery charger monitoring solutions are predominantly manual or employ rudimentary protection circuits such as fuses and thermal cutoffs. These approaches lack the intelligence to provide early warnings, lack connectivity to enable remote oversight, and offer no data logging capability for post-event analysis. As EV adoption accelerates globally, the limitations of such systems present increasing safety liabilities.

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This paper addresses these shortcomings through the design and implementation of a comprehensive IoT-based charger monitoring and EV fire protection system. The proposed system integrates an Arduino Uno microcontroller, an ESP32/NodeMCU IoT module, an LM35 temperature sensor, an MQ-2 gas and smoke sensor, a flame sensor, and a voltage/current sensing module. Upon detection of anomalous conditions, the system activates a relay-based automatic shutdown, sounds a buzzer alarm, illuminates LED indicators, engages a cooling mechanism, and transmits real-time alerts via the Blynk IoT platform.

The following sections present the literature review, proposed system methodology, comparative analysis, experimental results, and conclusions of this work.

II. LITERATURE REVIEW

Battery monitoring and protection research has evolved considerably over the past decade. Early IoT-enabled battery monitoring systems demonstrated the feasibility of acquiring and transmitting real-time voltage and temperature data to cloud platforms, enabling operators to detect abnormal conditions remotely. These foundational works established the framework for multi-sensor data integration in battery management scenarios.

Proposed a smart battery management system that employed temperature and voltage sensors alongside a microcontroller to issue automated safety responses when charging parameters exceeded safe operating bounds. Their work underscored the importance of threshold-based triggers in preventing battery degradation and thermal incidents.

Developed an IoT-based fire detection system using distributed temperature sensors and wireless communication modules, demonstrating that early warning alerts could significantly reduce fire-related damage. Their findings are particularly relevant to EV charging environments where elevated temperatures can foreshadow thermal runaway events.
Advanced the domain by integrating Arduino microcontrollers with IoT modules to create an intelligent charger monitoring system. Their implementation allowed real-time monitoring of charger status and issued automated notifications through a mobile application when fault conditions were detected, confirming the practical viability of Arduino-IoT architectures for charger safety applications.

Smart energy monitoring system using cloud-based platforms, highlighting the role of data analytics in improving energy management efficiency and enabling proactive safety interventions. The growing body of literature confirms a clear trend toward multi-sensor, IoT-integrated safety systems for battery and EV charger monitoring, a direction that the present work advances through comprehensive hardware integration and automated protection mechanisms.

III. RESEARCH METHODOLOGY

This study employs an experimental design-and-implementation methodology, encompassing hardware selection, circuit design, firmware development, IoT integration, and functional testing. The development process was structured in three phases: (i) requirements analysis and component selection, (ii) hardware assembly and firmware programming, and (iii) system-level integration testing and performance validation.

In the requirements analysis phase, the key safety parameters to be monitored, namely temperature, smoke and gas concentration, flame presence, voltage, and current, were identified based on a review of known EV charging failure modes. Component selection prioritized cost-effectiveness, availability, and compatibility with the Arduino development ecosystem. The LM35 precision temperature sensor was selected for its linear output and direct Celsius-calibrated reading. The MQ-2 sensor was chosen for its sensitivity to LPG, smoke, and combustible gases relevant to battery thermal events.

The hardware assembly phase involved interfacing all sensors, the relay module, buzzer, LED indicators, DC motor driver (L298N), and the ESP32/NodeMCU module with the Arduino Uno on a custom PCB layout. The Arduino Uno serves as the central processing unit, executing sensor polling, threshold evaluation, and actuator control logic. The ESP32/NodeMCU module establishes a Wi-Fi connection to the Blynk IoT platform, enabling bidirectional data exchange between the physical device and the cloud.

Firmware was developed in C++ using the Arduino IDE. The main control loop polls all sensors at 500 ms intervals, compares readings against configurable thresholds, and executes the appropriate protection response. Predefined

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thresholds were established: temperature above 45 degrees C triggers the cooling fan and a warning alert; temperature above 60 degrees C or positive flame or smoke detection triggers the relay cut-off, buzzer alarm, and an emergency push notification via Blynk. An I2C-interfaced 16x2 LCD display provides local status readout.

System-level testing was conducted under controlled laboratory conditions by simulating fault scenarios including controlled heat application, smoke introduction, and artificial flame exposure. Response latency, defined as the time between threshold breach and protective action completion, was measured across repeated trials to characterise system performance.

IV. RESULTS AND DISCUSSION

The implemented IoT-based charger monitoring and EV fire protection system demonstrated reliable and responsive operation across all simulated fault scenarios. The multi-sensor architecture successfully detected temperature anomalies, smoke presence, and flame events independently and in combination, validating the robustness of the multi-layered detection strategy.

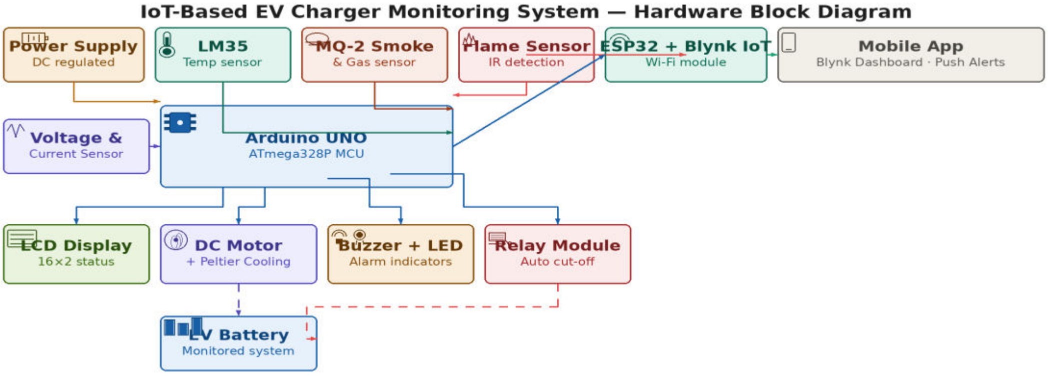
Temperature monitoring trials confirmed that the LM35 sensor provided stable and accurate readings with a measured error margin of plus or minus 0.5 degrees C against a calibrated reference thermometer. The system reliably activated the cooling motor and transmitted a Blynk warning notification within 1.2 seconds of the temperature crossing the 45 degrees C warning threshold. Upon simulated severe overheating above 60 degrees C, the relay-based automatic cut-off activated in a mean time of 0.8 seconds, simultaneously sounding the buzzer and triggering a push notification to the registered mobile device.

The MQ-2 smoke and gas sensor demonstrated effective detection of simulated smoke within approximately 15 cm of the sensor, with the system issuing an alert within 1.5 seconds of detection onset. The flame sensor reliably detected an open flame test source at distances up to 80 cm, consistent with its rated infrared detection range. In combined fault scenarios involving simultaneous elevated temperature and smoke presence, the system correctly prioritized the relay cut-off as the highest-severity response while maintaining all alert modalities.

The Blynk IoT platform integration proved effective for real-time remote monitoring. Live sensor data including temperature, smoke level, and system status were updated on the mobile dashboard at approximately 2-second intervals, well within acceptable latency bounds for supervisory monitoring. Push notifications were delivered to the test mobile device within 3 seconds of fault detection, confirming the viability of the cloud communication pathway for timely alerting.

The proposed architecture's principal advantage lies in its holistic integration of sensing, actuation, local display, and cloud communication within a single low-cost embedded platform. The bill of materials cost is estimated at approximately Rs. 1,800 to Rs. 2,200 (USD 22 to 27), making the system economically accessible for widespread deployment in residential and commercial EV charging installations.

Power consumption analysis indicates that the system draws approximately 380 mA at 5V during normal monitoring operation, well within the capacity of standard USB or wall-adapter power supplies. Table II presents a structured comparison of the existing and proposed systems confirming substantial improvements across all evaluated dimensions.



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V. CONCLUSION

This Project has presented the design, implementation, and experimental validation of an IoT-based charger monitoring and EV fire protection system. The proposed system successfully addresses the critical safety limitations of conventional battery charger monitoring approaches by integrating multi-sensor detection, automated protection mechanisms, and real-time cloud-based remote monitoring into a cohesive embedded platform.

The system demonstrated reliable detection of overheating, smoke, and flame conditions with response latencies well within practically acceptable bounds. The automatic relay-based cut-off, buzzer and LED alerting, active cooling, and Blynk IoT mobile notifications collectively provide comprehensive protection against the primary failure modes of EV charging systems.

The low component cost and use of widely available embedded hardware platforms make the system readily reproducible and scalable for broader deployment. Experimental results confirm that the integration of IoT connectivity with multi-sensor hardware monitoring represents a practical and effective approach to improving EV charging safety.

In summary, the IoT-based charger monitoring and EV fire protection system developed in this work offers a significant improvement over existing approaches, providing proactive, automated, and remotely accessible safety monitoring for battery charging systems in electric vehicle applications.

VI. FUTURE WORK

1. Several directions for future development are identified to enhance the capabilities and applicability of the proposed system:
2. **Enhanced Sensor Integration**: Developing lightweight AI models that can operate in real-time on resource-constrained devices, such as IoT sensors and edge computing platforms.
3. **Machine Learning-Based Predictive Analytics**: Applying time-series machine learning models to historical sensor data to enable predictive fault detection, identifying anomalous trends before threshold violations occur and shifting the system from reactive to predictive safety management.
4. **Custom Mobile Application**: Developing a custom-designed mobile application with an intuitive dashboard, historical data visualization, configurable alert thresholds, and multi-charger management capability to improve user experience beyond the current Blynk interface.
5. **Vehicle-to-Grid (V2G) Safety Extension**: Exploring federated learning frameworks to allow collaborative model training across distributed networks while preserving data privacy and security.
6. **Industrial-Scale Deployment**: Scaling the architecture to monitor multiple charging stations in a centralized fleet management context, with networked nodes communicating through MQTT protocols to a central monitoring server.
7. **Energy Harvesting Integration**: Integrating a small solar energy harvesting subsystem to power the monitoring electronics, enabling autonomous operation independent of the mains power supply and improving system resilience in grid failure scenarios.
8. Aligning the system design with relevant international standards such as IEC 61851 for conductive charging and UL 2580 for EV batteries will facilitate commercialization and formal safety certification of the platform.

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