

REAL-TIME MULTI-SENSOR FUSION FRAMEWORK FOR EARLY FAULT DETECTION IN ELECTRIC VEHICLE LITHIUM-ION BATTERIES

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Abstract: The power storage component that mainly powers electric vehicles (EVs) is lithium batteries due to their high performance, comparative durability, and excellent operational efficiency. However, there are chances of battery failures such as over temperature, over voltage, internal short circuit, gas leakage, and swelling, which can cause serious battery failures. Generally, Battery Management Systems (BMS) methods often use fewer sensing parameters, thus limiting the detection capabilities of battery faults. In this article, a real-time multi sensor fusion system will be proposed as an early warning system of lithium battery faults in electric vehicles. The multi sensor fault detection will be implemented using a rule-based algorithm, integrating voltage sensors, current sensors, temperature sensors, gas sensors, pressure sensors, and strain sensors. The developed system will be verified using Proteus IS software.

Keywords: Lithium-Ion Battery, Multi-Sensor Fusion, Thermal Runaway, Real-Time Monitoring.

I. INTRODUCTION

Electric vehicles (EVs) are gaining popularity these days because of their benefits to the environment and their high efficiency. Batteries used in electric vehicles are of lithium-ion type, and these are the main component of electric vehicles. Lithium-ion batteries are highly susceptible to electric, heat, and mechanical stress. Overcharge, overheat, short circuit, gas leakage, swelling, etc., may cause safety risks like thermal runaway and fire. The traditional Battery Management Systems (BMS) only consider the detection of voltage and temperature; however, such fault detection techniques may not be sufficient enough to detect faults because most of the faults relate to the combined effect of various parameters. Therefore, a real-time multi-sensor system is needed to enhance the detection accuracy. The proposed project aims to develop a real-time multi-sensor fusion system, which combines different types of voltage, current, temperature, gas, pressure, and strain sensors for the efficient monitoring of various battery systems. Thus, the system achieves higher safety, efficiency, and reliability

II. METHODOLOGY

The suggested system also adheres to a systematic approach to designing and deploying a real-time multi-sensor fusion model to early fault detection of lithium-ion batteries deployed in electric vehicles (EVs). The methodology will be sensor integration, data acquisition, signal processing, development of the fusion algorithm, fault classification and alert generation

1. System Design and Sensor Integration:

The initial one is the choice of suitable sensors that can be used to measure important parameters of the battery. Electrical parameters that are measured include voltage, current which is used to identify overcharge, deep discharge, and short circuit conditions. Thermal variations are monitored with the help of a temperature sensor (LM35) to detect overheating. An electrolyte decomposition and gas leakage are detected by a gas sensor (MQ series). Pressure and strain sensors are added that identify the increase in internal pressure and mechanical swelling of the battery. All the sensors are connected to an Arduino UNO microcontroller that will serve as the central processing unit. The sensor analogue outputs are linked to the 10-bit Arduino ADC channels (A0-A5) to get the data.

2. Data acquisition and Signal processing:

Permanently, the Arduino reads sensor analog signals. Calibration equations transform the raw ADC values to respective physical units.

For example:

- Scaling of voltage divider calculates voltage.
- Output of LM35 is used to derive temperature (10 mV/o C).
- The values of gas, pressure and strain are normalized to predetermined threshold.
- Simple filtering methods are used to stabilize and to minimize noises; these methods include averaging or delay based sampling.

3. Multi-Sensor Fusion Algorithm:

The decision-level fusion algorithm is performed on a rule basis after data acquisition. The algorithm does not consider parameters separately but analyzes combined variations of parameters. The threshold values are determined on the safe battery operating limits.

The fusion logic works in the following manner:

- When temperature exceeds 60-o C Thermal warning
- When the voltage is greater than what should be charged safely, then it is Overcharge condition.
- When the level of gases increases and pressure is increased, then Internal fault indication
- When strain and pressure change in line with each other → Swelling detection
- In case a particular combination of parameters becomes critical and passes the threshold limits, the system will consider the condition a fault.

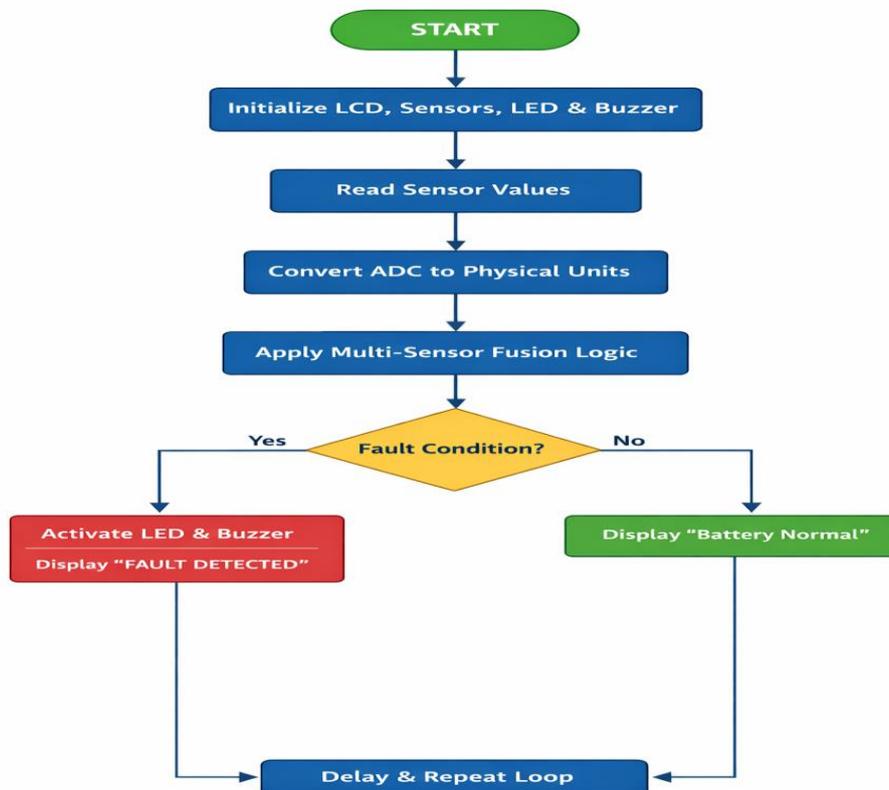


FIGURE: 1 REPRESENTS THE FLOW CHART FOR EV BATTERY DETECTION USING MULTI SENSORS

4. Fault Detection and Alert Mechanism.

When a fault is identified, the system comes on alert mechanisms including:

- Visual warning indicator (LED)
- Buzzer for audible alert

- LCD display of real-time status message

This provides real-time detection and preventative measure to prevent extreme damage or thermal runaway.

5. Simulation and Validation:

Proteus software is used to simulate the entire system. Adjustment of sensors inputs is used to artificially simulate various fault conditions like over-temperature, gas leakage and swelling. To test the accuracy of detection and the response time, the system response is studied.

III. RESULTS AND DISCUSSION

The proposed system of real-time multi-sensor fusion was adopted and tested in simulation in the normal condition and fault condition. In the normal operation, all the parameters of the battery such as voltage, current, temperature, gas level, pressure, and strain were within safe limits set beforehand. This system kept on checking these values and showed a Battery Normal status continuously without any warning indicators. This assures that it is running well and there are no false alarms. Under condition of fault, the system was able to detect abnormalities. The temperature rise above 60C was used to raise immediate fault detection, enabling the LED and the buzzer and providing a warning message in the LCD. Equally, high pressure and strain values along with high gas levels were rightfully recognized as internal battery faults (swelling or chemical wear). The system response time was about one second, which is an effective real-time performance. Generally the findings show that the multi-sensor fusion system is more precise in fault detection, quick response, and dependable monitoring as opposed to the conventional one-parameter system.

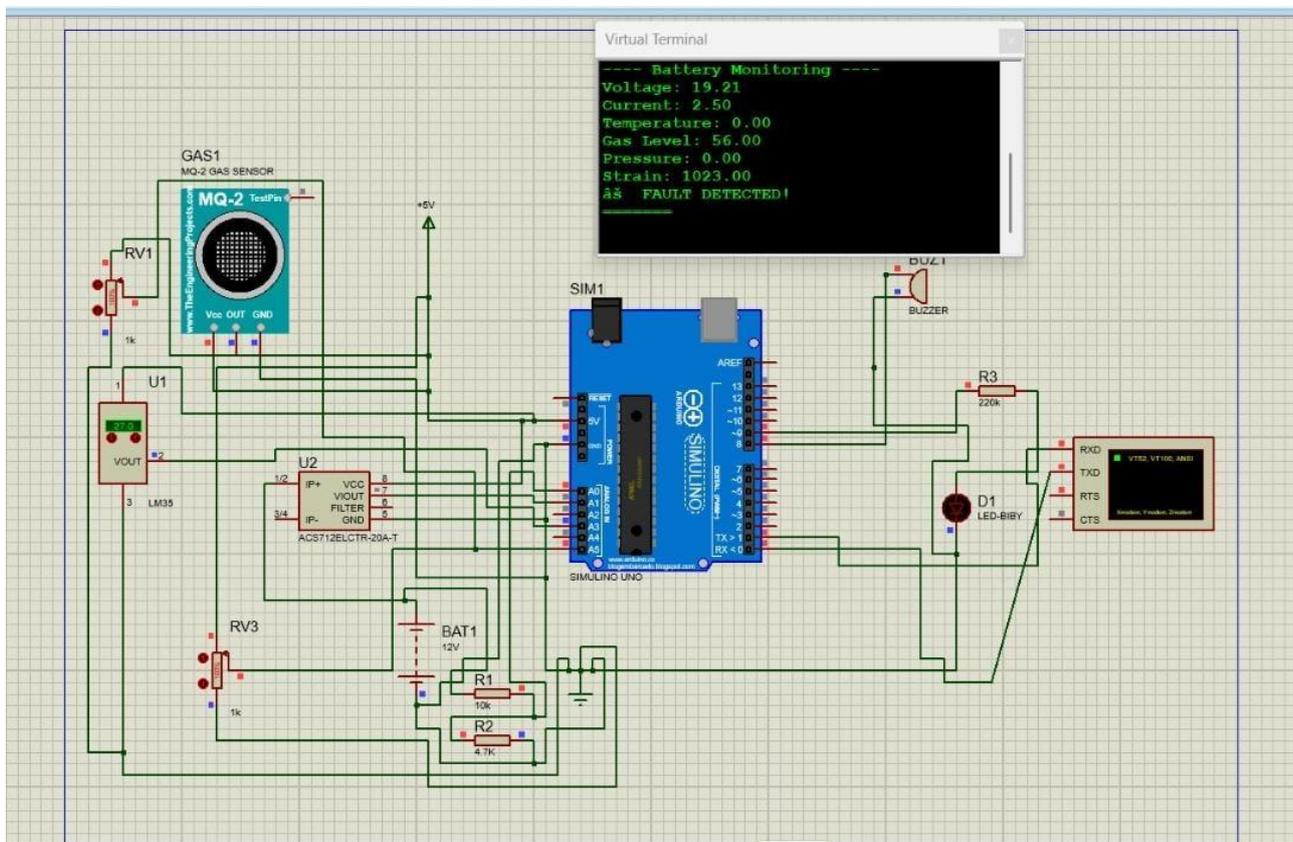


FIGURE: 2 SIMULATION OUTPUT FOR EV BATTERY DETECTION USING MULTI SENSORS

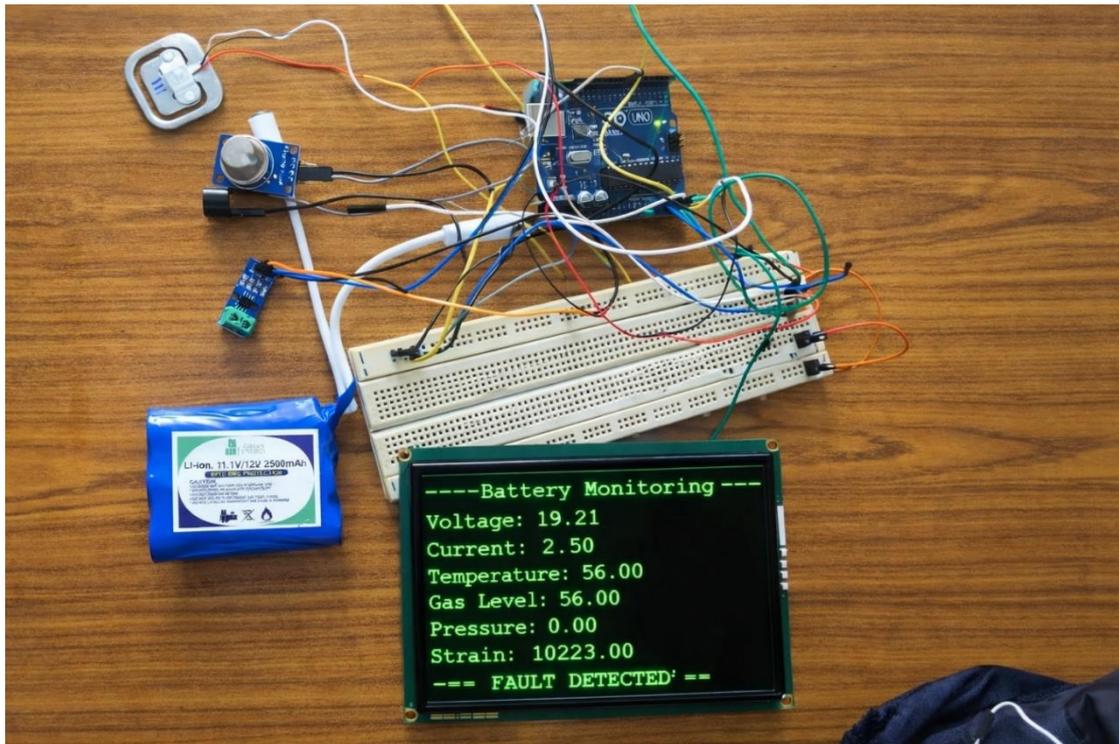


FIGURE: 3 HARDWARE IMPLEMENTATION FOR EV BATTERY DETECTION USING MULTI SENSORS

Discussion:

The experiment indicates that the suggested multi-sensor fusion model has a significant positive effect on the reliability of the detection of lithium-ion battery fault as compared to the traditional single-parameter monitoring measures. The system combines the electrical, thermal, chemical, and mechanical parameters to give a holistic view of the battery health. The suggested solution generates instant alerts of internal alterations (e.g., gas production and swelling) that do not necessarily have an instant impact on electrical sensors, unlike traditional Battery Management Systems (BMS) which operate primarily on the basis of voltage and temperature values. Through decision-level fusion, the accuracy of detection is improved as variations between multiple sensors are observed to determine the levels of detection and not single threshold violations. An increase in the levels of gas and pressure at the same time, is a strong indicator of internal chemical reactions, whereas a combined strain and pressure change are indications of swelling. With this multi-parameter analysis, the probability of missing faults is minimized and the ability of early warning is enhanced. Also, the system was found to have high response to time and consistency over the normal operating conditions, which proves that the system is fit to be used in real-time embedded applications. The cost-effectiveness and practicability of the system in terms of its use in battery packs of electric cars is maintained by the rule-based fusion algorithm being of low computational complexity. Nevertheless, the framework is based on the predetermined threshold values, and they can be different according to the battery chemistry and capacity. Different types of batteries should have the right calibration in order to optimize performance. To improve this in the future, there can be adaptive thresholds or machine learning to enhance predictions. In general, the discussion demonstrates that the proposed multi-sensor fusion solution can be a useful and effective method to achieve the higher safety of lithium-ion battery usage in electric vehicles.

IV. CONCLUSION

The suggested multi-sensor fusion framework in real-time is an efficient and dependable solution to the problem of early fault detection in lithium-ion batteries in electric vehicles. The system uses various sensing modalities (voltage, current, temperature, gas emission, pressure, and strain) to give a global perspective of battery health, which is not the case with the current Battery Management Systems (BMS), which uses single-parameter measurements as the primary model. The rule-based fusion algorithm compares changes between electrical, thermal, chemical, and mechanical parameters and allows classifying significant fault conditions like overcharge, overheating, internal gas formations, and structural swelling before turning into dangerous failures. The effectiveness of the proposed approach is confirmed by the simulation results which test the proper classification of the faults, minimal false alarm in the regular working conditions, and the response time which is only a second in the abnormal working conditions. Reality time monitoring

with minimal computational complexity is ensured by the implementation based on a cost-effective embedded platform, making the system convenient to be practically implemented in EV battery packs. Also, the combination of visual, audible, and display-based warning features improves the awareness of the user and allows timely preventive measures in case of possible safety hazards, including thermal runaway and fire. All in all, the strategy of multi-sensor fusion contributes greatly to the reliability, safety and robustness of the lithium-ion battery monitoring systems. The functionality of the framework in terms of correlated multi-parameter analysis allows offering early warning and, thus, prolonging the life of the battery and providing a safer driving experience in electric cars. The suggested system is therefore a scalable and effective basis of next-generation intelligent BMS architectures that will deliver better battery safety and performance in the field of EV application.

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