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REAL-TIME EMBEDDED BATTERY MONITORING AND FAULT DETECTION USING MACHINE LEARNING

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Abstract: This paper presents a real-time embedded battery monitoring and fault detection system implemented using Arduino Uno and a lightweight machine learning approach. The system continuously monitors voltage, current, and temperature parameters of a 12 V lead-acid battery using INA219 and NTC thermistor sensors. A logistic regression–based model is trained offline using synthetic datasets and deployed on the embedded platform for real-time decision making. The measured parameters are processed locally without cloud dependency, allowing efficient and low-cost standalone operation. Experimental results demonstrate reliable detection of abnormal operating conditions such as low voltage, high current, and increased temperature. The proposed system achieves low computational overhead, fast execution, and real-time response suitable for resource-constrained embedded systems.

***Index Terms* -** Arduino Uno, INA219 Sensor, NTC Thermistor, LCD Display, Battery Monitoring, Fault Detection, Embedded System, Logistic Regression, Machine Learning, Real-Time Monitoring, Normal and Abnormal.

I. INTRODUCTION

Battery-powered systems are widely used in applications such as renewable energy storage, backup power systems, electric vehicles, industrial automation, and portable electronic devices. The performance and reliability of these systems mainly depend on the operating condition and health of the battery. Among different battery technologies, lead-acid batteries are commonly used because of their low cost, simple construction, and high reliability. However, improper operating conditions such as over-discharge, excessive current flow, and high temperature can reduce battery life and may lead to system failure.

Conventional battery monitoring systems generally use fixed threshold methods for detecting abnormal conditions. Although these methods are simple to implement, they are not capable of adapting to varying real-time operating conditions. As a result, they may produce false alarms or fail to detect early-stage faults. Recent advancements in embedded systems and machine learning techniques have enabled the development of intelligent monitoring systems capable of performing data-driven decision making in real time.

This paper presents a real-time embedded battery monitoring and fault detection system using Arduino Uno and a lightweight machine learning approach. The system continuously monitors important battery parameters such as voltage, current, and temperature using an INA219 sensor and an NTC thermistor. A logistic regression–based model is trained offline using synthetic datasets and deployed on the Arduino for real-time fault detection. The proposed system performs all computations locally without relying on cloud infrastructure or external processing, making it suitable for low-cost and standalone embedded applications.

The developed system provides real-time monitoring, fast response, low computational complexity, and reliable fault detection. The measured parameters and operating condition are displayed on a 16×2 LCD module, enabling easy visualization and user interaction. The proposed approach demonstrates that lightweight machine learning techniques can be effectively integrated into embedded systems for intelligent battery condition monitoring and early fault detection.

II. LITERATURE SURVEY

Various battery monitoring and fault detection systems have been developed using embedded systems and machine learning techniques. Traditional monitoring methods mainly use fixed threshold values for voltage and current, but these methods are not effective in detecting early abnormal conditions.

Recent approaches use machine learning algorithms such as Artificial Neural Networks (ANN), Support Vector Machines (SVM), and Logistic Regression for intelligent fault detection. Deep learning models provide high accuracy but require large datasets and high computational resources, making them less suitable for low-cost embedded systems.
IoT-based battery monitoring systems also enable remote monitoring and cloud-based analysis, but they increase system complexity and dependency on internet connectivity.

Among different techniques, logistic regression is suitable for embedded applications because of its simple mathematical operations and low computational requirements. Therefore, the proposed system uses a lightweight logistic regression–based approach for real-time battery monitoring and fault detection using Arduino Uno.

III. SYSTEM DESIGN

The proposed system is designed using Arduino Uno as the main processing unit. The system continuously monitors battery parameters such as voltage, current, and temperature using suitable sensors. An INA219 sensor is used for measuring voltage and current, while an NTC thermistor is used for temperature sensing.

The acquired sensor values are processed by the Arduino Uno using a logistic regression–based machine learning model. The trained model parameters are embedded into the Arduino program for real-time fault detection. A 16×2 LCD display with I2C interface is used to display the measured parameters and system status.

The complete system operates as a standalone embedded platform without requiring cloud connectivity or external processing. This design ensures low cost, real-time performance, and reliable operation for battery monitoring applications.

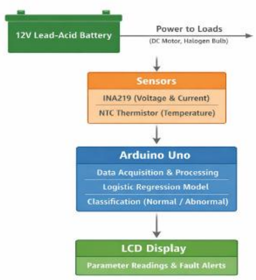

Fig 1: *Proposed Embedded Battery Monitoring System Architecture*

IV. WORKING METHODOLOGY

The system continuously acquires voltage, current, and temperature values from the connected sensors. The measured data is processed by the Arduino Uno and normalized using predefined parameters obtained during model training.

A logistic regression–based model is used for evaluating the battery condition. The model computes a weighted combination of input parameters and applies a sigmoid function to generate an output between 0 and 1.

$$\sigma(z) = \frac{1}{1 + e^{-z}}$$

The weighted input is calculated as:

$$z = w \cdot x + b$$

Based on the output value, the system identifies whether the operating condition is normal or abnormal. If any abnormal condition such as low voltage, excessive current, or high temperature is detected, the system displays a fault indication on the LCD module. The entire process is performed in real time using embedded processing without external computation or cloud support.

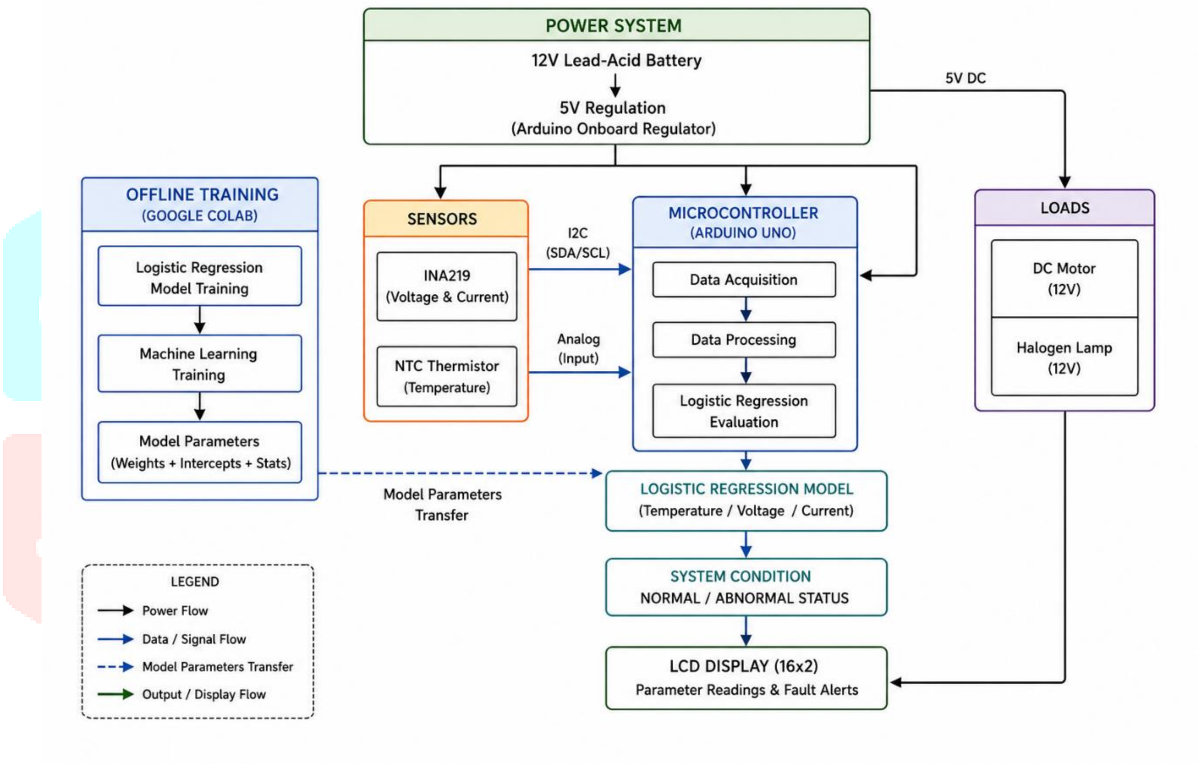

Fig 2: Data Processing and Decision Flow

V. MACHINE LEARNING IMPLEMENTATION

The proposed system uses a logistic regression–based machine learning model for real-time fault detection. The model is trained offline using Python and the scikit-learn library in Google Colab. Synthetic datasets are generated within practical operating ranges of voltage, current, and temperature.

Before training, the input parameters are normalized to improve model performance and consistency. The logistic regression model learns the relationship between sensor inputs and battery operating conditions. After training, the obtained weights and bias values are extracted and embedded into the Arduino program as fixed constants.

During real-time operation, the Arduino Uno acquires sensor data and performs only inference operations using the stored parameters. The prediction process involves simple arithmetic calculations and sigmoid function evaluation, resulting in low computational overhead and fast execution. This lightweight implementation makes the model highly suitable for embedded systems with limited memory and processing capability.

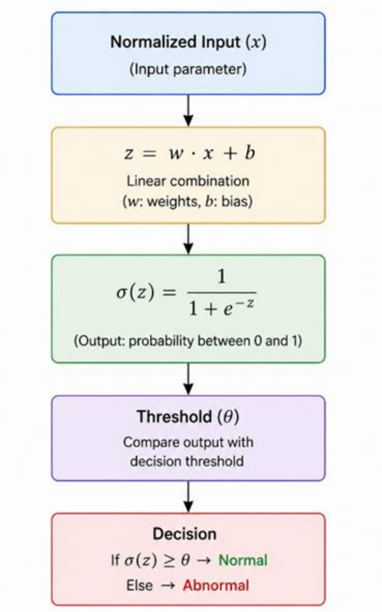

Fig 3: Logistic Regression Decision Process

VI. RESULTS AND DISCUSSION

The proposed system was tested under different operating conditions using a 12 V lead-acid battery and practical loads. The INA219 sensor successfully measured voltage and current, while the NTC thermistor monitored temperature in real time.

The logistic regression model correctly detected abnormal conditions such as low voltage, high current, and increased temperature. The Arduino Uno processed the sensor data efficiently with minimal delay, demonstrating reliable real-time performance.

The measured parameters and system status were displayed clearly on the 16×2 LCD module. The overall system showed low computational complexity, stable operation, and effective fault detection suitable for embedded battery monitoring applications.

VII. ADVANTAGES

The developed system was tested under different load conditions using a DC motor and halogen lamp. The sensor readings remained stable during normal operation and responded accurately under abnormal conditions such as low voltage, high temperature, and excessive current. The logistic regression model successfully classified battery conditions in real time. The Arduino Uno processed the sensor data with minimal delay, ensuring reliable and efficient embedded operation. The 16×2 LCD display clearly showed the battery parameters and fault indications, enabling easy real-time monitoring of the system.

VIII. CONCLUSION

The proposed system successfully implements real-time battery monitoring and fault detection using Arduino Uno and logistic regression. The system continuously monitors voltage, current, and temperature parameters and identifies abnormal operating conditions effectively. The lightweight machine learning implementation provides fast execution with low computational overhead, making it suitable for embedded applications. The developed system offers a reliable, low-cost, and efficient solution for intelligent battery monitoring and real-time fault detection.

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