AI-Enabled Wireless Predictive Battery Health Monitoring System for Electric Vehicles

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Abstract-*The exponential growth of electric vehicles (EVs) necessitates reliable, smart, and cost-effective battery monitoring systems. This paper proposes an innovative AI-enabled, wireless Lithium-ion battery packs used in electric vehicles are managed by a battery management system (BMS). Our design integrates edge computing with machine learning to enable real-time, predictive health monitoring and early fault detection. Wireless sensors gather critical parameters such as temperature, voltage, and gas emissions, transmitting data to a central edge device running lightweight AI models. In the event of possible failure situations such as gas leaking or thermal runaway, proactive actions such as motor shut-off and alert notifications are initiated. The system not only ensures enhanced safety but also provides a scalable and affordable alternative for next-generation EVs.*

Keywords- Battery Management System, Electric Vehicles, Edge AI, Wireless Sensors, Predictive Maintenance, Thermal Runaway

I. INTRODUCTION

As electric vehicles (EVs) become mainstream Lithium-ion battery dependability and safety have become major issues have emerged as critical concerns. Traditional BMS units respond to abnormal situations slowly since they mostly rely on threshold-based monitoring with connected sensor connections and little intelligence.

Given the dangers of overheating, gas leaks, and cell degradation, an intelligent system capable of real-time prediction and prevention is essential. This project aims to bridge that gap by designing an AI-enabled wireless battery health monitoring system using edge computing to detect and mitigate risks proactively.

II. EXISTING SYSTEM

Traditional battery protection systems rely heavily on microcontrollers like the ATmega328P and a combination of temperature and gas sensors to monitor conditions locally. These systems activate cooling mechanisms or cut power when thresholds are exceeded. While effective for basic safety, they are reactive rather than predictive and lack scalability. Wired configurations increase complexity and cost, while the absence of AI limits the system's ability to learn or adapt to varying conditions.

III. LITERATURE SURVEY

Several works have discussed BMS architecture and battery safety. Studies include:

- Use of OBD-based diagnostics for fault detection in power batteries.
- Hybrid material designs for improved thermal safety.
- AI techniques like LSTM for voltage anomaly detection.
- Integration of fire suppression mechanisms.
- Wireless sensor networks for battery condition monitoring.

While significant, these solutions lack a combined approach that leverages edge AI, wireless flexibility, and predictive capabilities for battery safety.

IV. PROPOSED SYSTEM

A. System Overview

The proposed system consists of distributed wireless sensor nodes measuring parameters such as temperature, gas concentration, and voltage. These nodes transmit data via Wi-Fi to a central edge computing device (ESP 8266). The edge device runs an ML-based anomaly detection model. It provides alerts and turns on pertinent actuators, such as solenoids or cooling fans, when it notices unusual activity.

B. BLOCK DIAGRAM

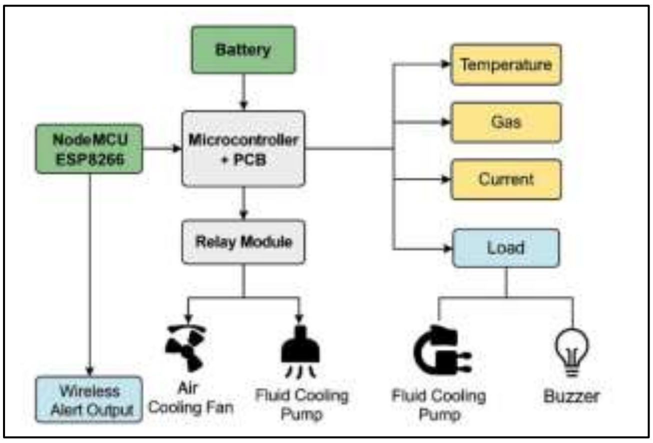

Fig:1. Block Diagram

C. PCB Layout and Circuit

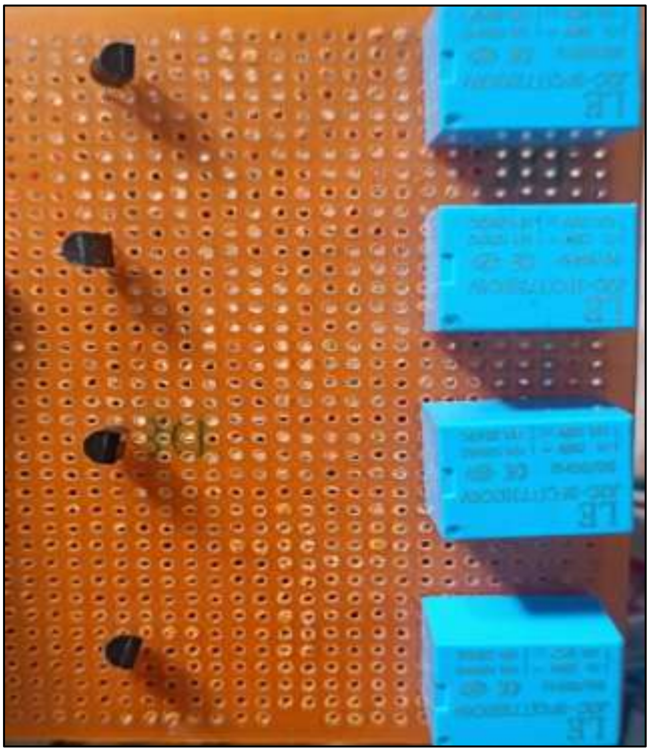

Fig:2. PCB Board

Design involves compact PCBs for sensor nodes and a central board with AI capability. A power module, a Wi-Fi module, and the sensor are all included in each sensor node. The edge board includes a microcontroller, power management IC, and communication interfaces.

D. CIRCUIT DIAGRAM

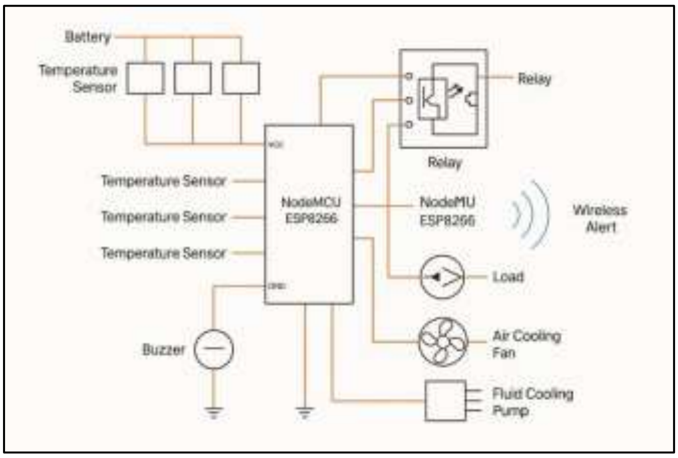

Fig:3. Circuit Diagram

V. HARDWARE COMPONENTS

- Controller: ESP 8266
- Sensors: DHT-11 (Temperature), MQ2 (Gas), PT96 (Voltage Regulator)
- Wireless Modules: In-built Wi-Fi in ESP8266
- Display: Smartphone
- Actuators: 5V Relay, Cooling Fan(F8025), Solenoid Valve, Buzzer, Fluid Cooling Pump, Bulb (100W / 0.5W)
- Power Supply: 12V 2A Lithium-Ion Pack with Protection Circuit

VI. SOFTWARE AND MACHINE LEARNING

A. Data Collection

We collected normal and fault-condition data from lab-simulated battery environments using sensors connected to ESP8266.

B. Model Selection

An Isolation Forest model was chosen for its suitability in real-time anomaly detection on limited computational hardware.

C. Training and Deployment

Data was preprocessed and trained using Python (scikit-learn). The model was then converted using Edge Impulse or TensorFlow Lite Micro and deployed to ESP8266.

D. Workflow

Sensor → Data Preprocessing → Anomaly Detection → Action Trigger → Logging/Alert

VII. WORKING PRINCIPLE

- If temperature < 40°C and gas concentration < threshold, system displays "Ready to Go" and motor runs.
- If temperature > 45°C, cooling fan turns on and Pump . At 50°C, system stops motor and shows "Ignition Off."
- If gas > threshold, solenoid activates and motor shuts off.
- If ML model detects anomaly before threshold is reached, pre-emptive action is taken.

Fig:4. HardWare Set-up Full View

VIII. APPENDIX - DATA COLLECTION & ML CODE:

```
# Sensor Data Simulation (Python for ESP8266)

import random, time

import pandas as pd


data = []

for _ in range(1000):

    temp = random.uniform(25, 45)

    gas = random.uniform(50, 300)

    voltage = random.uniform(3.0, 4.2)

    label = 'anomaly' if temp > 40 or gas > 250 else 'normal'

    data.append([temp, gas, voltage, label])

    time.sleep(0.1)


# Save to CSV

pd.DataFrame(data, columns=['temp', 'gas', 'voltage', 'label']). to_csv('battery_data.csv', index=False)

# ML Model Training (Python - Scikit-learn)

import pandas as pd

from sklearn.ensemble import IsolationForest

from sklearn.preprocessing import StandardScaler

import joblib


data = pd.read_csv('battery_data.csv')

features = data[['temp', 'gas', 'voltage']]

scaler = StandardScaler()

X = scaler.fit_transform(features)


model = IsolationForest(contamination=0.1)

model.fit(X)
```

```
# Save model and scaler
joblib.dump(model, 'model.pkl')
joblib.dump(scaler, 'scaler.pkl')
# ESP8266 AI Inference (Pseudocode)
read sensors → normalize values → run inference (Isolation Forest logic) → trigger action if anomaly
```

IX. ADVANTAGES

- Wireless, scalable design reduces wiring complexity.
- AI-based early detection improves safety.
- Edge inference allows real-time operation without cloud dependence.
- Cost-effective components enable low-budget implementation.
- Portable, suitable for retrofitting existing EVs.

X. CONCLUSION

This research demonstrates a smart, wireless battery management system that leverages edge computing and AI for predictive safety. Unlike threshold-based approaches, our system anticipates faults and takes action before they manifest critically. The integration of lightweight AI models on microcontrollers, wireless sensors, and safety actuators forms a practical and scalable solution for modern EVs.

XI. REFERENCES

1. Salamati, S. M., Huang, C. S., Balagopal, B., & Chow, M. Y. (2018, January). Experimental battery monitoring system design for electric vehicle applications. In 2018 IEEE International Conference on Industrial Electronics for Sustainable Energy Systems (IESES) (pp. 38-43). IEEE.
2. Pattnaik, M., Badoni, M., & Singh, H. P. (2021, October). Analysis of electric vehicle battery system. In 2021 4th International Conference on Recent Developments in Control, Automation & Power Engineering (RDCAPE) (pp. 540-543). IEEE.
3. Brandl, M., Gall, H., Wenger, M., Lorentz, V., Giegerich, M., Baronti,. (2012, March). Batteries and battery management systems for electric vehicles. In 2012 Design, Automation & Test in Europe Conference & Exhibition (DATE) (pp. 971-976). IEEE.
4. Ahmed, R., Gazzarri, J., Onori, S., Habibi, S (2015). Model-based parameter identification of healthy and aged li-ion batteries for electric vehicle applications. SAE International Journal of Alternative Powertrains, 4(2), 233-247.
5. Rezvanizaniani, S. M., Liu, Z., Chen, Y., & Lee, J. (2014). Review and recent advances in battery health monitoring and prognostics technologies for electric vehicle (EV) safety and mobility. Journal of power sources, 256, 110-124.
6. Divakar, B. P., Cheng, K. W. E., Wu, H. J., Xu, J., Ma, H. B., Ting, W., ... & Leung, C. H. (2009, May). Battery management system and control strategy for hybrid and electric vehicle. In 2009 3rd international conference on power electronics systems and applications (PESA) (pp. 1-6). IEEE.
7. Abd Wahab, M. H., Anuar, N. I. M., Ambar, R., Baharum, A., Shanta, S., Sulaiman, M. S., & Hanafi, H. F. (2018). IoT-based battery monitoring system for electric vehicle. International Journal of Engineering & Technology (IJET), 7(4.31), 505-510.
8. Mathew, S. A., Prakash, R., & John, P. C. (2012, November). A smart wireless battery monitoring system for electric vehicles. In 2012 12th International Conference on Intelligent Systems Design and Applications (ISDA) (pp. 189-193). IEEE.
9. Hannan, M. A., Lipu, M. H., Hussain, A., & Mohamed, A. (2017). A review of lithium-ion battery state of charge estimation and management system in electric vehicle applications: Challenges and recommendations. Renewable and Sustainable Energy Reviews, 78, 834-854.
10. Lipu, M. H., Hannan, M. A., Karim, T. F., Hussain, A., Saad, M. H. M., Ayob, A., ... & Mahlia, T. I. (2021). Intelligent algorithms and control strategies for battery management system in electric vehicles: Progress, challenges and future outlook. Journal of Cleaner Production, 292, 126044.
11. Zhang, Y., Li, T., Yan, X., Wang, L., Zhang, J., Diao, X., & Li, B. (2021). Electric vehicle charging fault monitoring and warning method based on battery model. World Electric Vehicle Journal, 12(1), 14.
12. Kumar, P. S., Kamath, R. N., Boyapati, P., Josephson, P. J., Natrayan, L., & Shadrach, F. D. (2022). IoT battery management system in electric vehicle based on LR parameter estimation and ORMeshNet gateway

topology. Sustainable Energy Technologies and Assessments, 53, 102696.

13. Laadjal, K., & Cardoso, A. J. M. (2021). Estimation of lithium-ion batteries state-condition in electric vehicle applications: issues and state of the art. Electronics, 10(13), 1588.
14. Mishra, S., Swain, S. C., & Samantaray, R. K. (2021, October). A Review on Battery Management system and its Application in Electric vehicle. In 2021 International Conference on Advances in Computing and Communications (ICACC) (pp. 1-6). IEEE.
15. Rahimi-Eichi, H., Ojha, U., Baronti, F., & Chow, M. Y. (2013). Battery management system: An overview of its application in the smart grid and electric vehicles. IEEE industrial electronics magazine, 7(2), 4-16.
16. Adaikkappan, M., & Sathiyamoorthy, N. (2022). Modeling, state of charge estimation, and charging of lithium-ion battery in electric vehicle: a review. International Journal of Energy Research, 46(3), 2141-2165.
17. Senthilkumar, M., Suresh, K. P., Sekar, T. G., & Pazhanimuthu, C. (2021, March). Efficient battery monitoring system for E-vehicles. In 2021 7th International Conference on Advanced Computing and Communication Systems (ICACCS) (Vol. 1, pp. 833-836). IEEE.
18. Hua, C. C., & Lin, M. Y. (2000, December). A study of charging control of lead-acid battery for electric vehicles. In ISIE'2000. Proceedings of the 2000 IEEE International Symposium on Industrial Electronics (Cat. No. 00TH8543) (Vol. 1, pp. 135-140). IEEE.
19. Li, L., Li, Z., Zhao, J., & Guo, W. (2018). Lithium-ion battery management system for electric vehicles. International Journal of Performability Engineering, 14(12), 3184.
20. Meissner, E., & Richter, G. (2003). Battery monitoring and electrical energy management: Precondition for future vehicle electric power systems. Journal of power sources, 116(1-2), 79-98.
21. Afonso, J. A., Sousa, R. A., Ferreira, J. C., Monteiro, V., Pedrosa, D., & Afonso, J. L. (2017, September). IoT system for anytime/anywhere monitoring and control of vehicles' parameters. In 2017 IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI) (pp. 193-198). IEEE.
22. Shete, S., Jog, P., Kumawat, R. K., & Palwalia, D. K. (2021, December). Battery management system for soc estimation of lithium-ion battery in electric vehicle: a review. In 2021 6th IEEE International Conference on Recent Advances and Innovations in Engineering (ICRAIE) (Vol. 6, pp. 1-4). IEEE.
23. Shah, F. A., Sheikh, S. S., Mir, U. I., & Athar, S. O. (2019, August). Battery health monitoring for commercialized electric vehicle batteries: Lithium-ion. In 2019 International Conference on Power Generation Systems and Renewable Energy Technologies (PGSRET) (pp. 1-6). IEEE.
24. Cuma, M. U., & Koroglu, T. (2015). A comprehensive review on estimation strategies used in hybrid and battery electric vehicles. Renewable and Sustainable Energy Reviews, 42, 517-531.
25. Morello, R., Di Rienzo, R., Roncella, R., Saletti, R., Schwarz, R., Lorentz, V. R., ... & Baronti, F. (2018, October). Advances in li-ion battery management for electric vehicles. In IECON 2018-44th Annual Conference of the IEEE Industrial Electronics Society (pp. 4949-4955). IEEE.
26. Samikannu, R., Yahya, A., Tariq, M. U., Asim, M., & Babar, M. (2023). IoT based battery energy monitoring and management for electric vehicles with improved converter efficiency. Plos one, 18(10), e0286573.
27. Tifour, B., Boukhnifer, M., Hafaifa, A., & Tanougast, C. (2020). Monitoring and control of energy management system for fuel cell hybrid in electrical vehicle using fuzzy approach. Diagnostyka, 21.
28. Zhao, J., & Burke, A. F. (2022). Electric vehicle batteries: Status and perspectives of data-driven diagnosis and prognosis. Batteries, 8(10), 142.
29. Buenestado, P., Gibergans-Báguena, J., Acho, L., & Pujol-Vázquez, G. (2023). Predictive speed control of a DC universal motor applied to monitor electric vehicle batteries. Machines, 11(7), 740.
30. Asaad, M., Ahmad, F., Alam, M. S., & Rafat, Y. (2017, August). IoT enabled electric vehicle’s battery monitoring system. In The 1st EAI International Conference on Smart Grid Assisted Internet of Things (pp. 1-10).