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Smart Battery Monitoring System for EV Two Wheelers

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ABSTRACT

BACKGROUND: The increased popularity of electric two-wheelers has underscored the need for robust solutions to monitor and manage battery performance, as battery failures can affect vehicle reliability and safety. Proactive monitoring using technology-driven approaches is essential to extend battery lifespan and ensure operational efficiency, especially in settings with varied usage patterns and environmental conditions.

AIM: This study evaluates the utility and performance impact of implementing a smart battery monitoring system (SBMS) tailored for electric two-wheelers, with a focus on real time data collection, early warning of battery issues, and optimized maintenance scheduling. **MATERIALS AND METHODS:** Over a five-year period (2020–2024), 1200 electric two wheelers were retrofitted with an IoT-based SBMS at selected sites in Punjab. The system continuously tracked critical battery parameters—such as voltage, temperature, state of charge, and state of health—through wireless sensors. Collected data were processed and analyzed to assess the frequency and cause of alerts, maintenance interventions, and any reduction in unplanned breakdowns.

RESULT: The SBMS facilitated the early detection of deteriorating battery health and potential safety risks, resulting in a 30% decrease in unexpected vehicle breakdowns. Actionable alerts regarding battery status were identified in 18.5% of vehicles. Analysis of user engagement indicated a higher frequency of system usage among male riders, with younger users (below 30 years) receiving more technical alerts. The system recorded increased alerts during warmer months, emphasizing the importance of thermal management in battery safety.

Keywords: Smart Battery Monitoring; Electric Two Wheeler; Battery Health; IOT; Predictive Maintenance; Real-Time Diagnostics; EV Safety health

INTRODUCTION

The rising adoption of electric two-wheelers has introduced new challenges in battery management and vehicle reliability, which are critical for sustainable urban transportation. Batteries in electric vehicles (EVs), particularly lithium-ion types, are essential components yet pose significant risks such as degradation, overheating, and unexpected failures. These challenges have drawn considerable attention worldwide due to their implications for performance, safety, and environmental impact. With increased EV penetration in countries like India, where traffic density and varying road conditions prevail, effective battery monitoring has become indispensable.

Electric two-wheelers utilize batteries that require constant monitoring to ensure optimal performance and longevity. Battery monitoring systems (BMS) cover parameters such as voltage, current, temperature, and state of health (SOH), playing a significant role in balancing cells and preventing failures. Recent advancements in IOT and sensor technologies have enabled real-time battery health diagnostics, thus facilitating predictive maintenance and safety enhancements.

Different battery management technologies and architectures exist, ranging from simple threshold-based alerts to complex AI powered predictive models. The state-

of charge (SOC) and state-of-health (SOH) estimations form core assessments in battery management, affecting vehicle range and operational reliability. System performance is influenced by user behavior, environmental factors like temperature, and battery chemistry, making the precise monitoring approach necessary.

This research investigates the design and implementation of a smart battery monitoring system for EV two-wheelers, examining its effectiveness in early fault detection, predictive maintenance, and safety improvements. The study aims to address battery management challenges faced in real-world operating conditions, contributing to enhanced vehicle reliability and user confidence.

MATERIALS & METHODS

This retrospective study was conducted over five years, from January 2020 to December 2024, involving electric two-wheelers equipped with a smart battery monitoring system (SBMS) deployed in Punjab, India. The study aimed to evaluate the effectiveness and functionality of the SBMS in tracking battery parameters under real world conditions. A total of 1200 electric two-wheelers, both privately owned and from commercial fleets, were included in the study. The monitoring system consisted of voltage, current, and temperature sensors integrated with a Node MCU microcontroller with Wi-Fi connectivity for real-time data transmission.

Inclusion Criteria: Electric two-wheelers equipped with the complete SBMS package, including voltage, current, and temperature sensors with wireless monitoring capability, were considered for data analysis.

Exclusion Criteria: Two-wheelers lacking any of the critical SBMS components or those without consistent data logging over the study period were excluded from the study.

The data collected through the IOT platform was analyzed to identify battery health status, early warning signals, and in 22% of total vehicles during the study period. Among these, 18% were related to over-temperature warnings, while 10% showed early signs of state-of-health.

overall effectiveness of the system in reducing unplanned battery failures.

RESULT

The current study was carried out over a period of five years, from January 2020 to December 2024, across the Punjab region, focusing on electric two-wheelers equipped with a smart battery monitoring system (SBMS). A total of 1200 electric two wheelers from various owns and commercial fleets were monitored for battery health and performance parameters.

The highest number of battery alerts and maintenance interventions was recorded in 2022, followed by 2023 and 2021. The year 2020 recorded the least number of incidents related to battery faults or degradation. The SBMS identified critical battery health issues

User engagement analysis revealed that male riders reported higher interaction with the monitoring system's interface, while younger riders (<30 years) experienced more frequentbattery health alerts. Seasonal trends indicated increased battery stress and alert frequency during the summer months, with a reduction during winter.

Overall, the implementation of SBMS was associated with a significant 30% reduction in unexpected battery failures and enhanced battery lifecycle management. trends indicated increased battery stress and performance degradation during periods of extreme heat. This stress pattern was closely linked to consistent high-demand usage, such as frequent rapid acceleration and sustained high speeds. Consequently, the system began issuing pre emptive alerts to encourage reduced power draw during peak temperature hours. By leveraging these insights, maintenance schedules were dynamically adjusted to pre-emptively address wear-related issues. This proactive approach further solidified the 30% failure reduction and contributed to a more reliable rider experience.

Table 1: Annual Statistics of Battery Alerts, Maintenance Events, and Co-Alert Rates for Smart Battery Monitoring System in Electric Two Wheelers (2020–2024)

YEAR	Total No. of Vehicles Monitored	Over temperature Alerts	Early SOH Degradation Alerts	Total Alerts	Maintenance Interventions	Co occurrence of Multiple Alerts
2020	150	18 (12.0%)	8 (5.3%)	26 (17.3%)	14 (9.3%)	2 (1.3%)
2021	245	28 (11.4%)	15 (6.1%)	43 (17.5%)	22 (9.0%)	3 (1.2%)
2022	320	54 (16.9%)	27 (8.4%)	81 (25.3%)	35 (10.9%)	6 (1.9%)
2023	284	41 (14.4%)	33 (11.6%)	74 (26.1%)	29 (10.2%)	4 (1.4%)
2024	201	32 (15.9%)	21 (10.4%)	53 (26.4%)	16 (8.0%)	2 (1.0%)
TOTAL	1200	173(14.4%)	104(8.7%)	277(23.1%)	116(9.7%)	17(1.4%)

Monthly analysis of alert rates indicated battery|likely due to decreased vehicle usage. In 2024, over-temperature and degradation alerts peakedspikes in technical alert rates were found not only during the summer months, with the highestin June and July but also in December, proportions observed in May, June, and July for thecorresponding to significant changes in ambient years 2022 and 2023. In both 2020 and 2021, a declinetemperature.
in the number and percentage of alerts was reported

Table 2: Age-wise Distribution of Battery Alerts in Electric Two-Wheelers with Smart Battery Monitoring System (2020–2024

Distribution of Over-temperature Alerts

Age Group (years)	2020	2021	2022	2023	2024	TOTAL
0-20	5	8	12	9	7	41
21-30	7	12	22	18	14	73
31-40	4	4	10	10	6	34
41-50	1	2	5	3	3	14
>50	1	2	5	1	2	11
Total	18	28	54	41	32	173

Table 3: Age-wise Distribution of Early SOH Degradation Alerts in Electric Two Wheelers (2020–2024)

Age Group (years)	2020	2021	2022	2023	2024	TOTAL
0-20	2	3	4	3	2	14
21-30	4	6	10	8	9	37
31-40	1	3	6	5	3	18
41-50	1	2	4	2	3	12
>50	0	1	3	1	4	9
Total	8	15	27	19	21	90

Among these age groups, battery alerts were more frequent in users aged 21–30 years (40.6%) and 31–40 years (23.5%), indicating that younger and mid-aged users experience higher system notifications. Male users accounted for 62% of total alerts, while
female users accounted for 38%, suggesting
higher EV usage or engagement among males. Co-occurrence of multiple alerts was
most commonly reported in the 21-30 age group.Analysis of system alert data reveals distinct user engagement patterns. Notifications are most prevalent among younger and middle-aged demographics, with the 21-30 age group responsible for 40.6% of all alerts, followed by users aged 31-40 at 23.5%.

Furthermore, a significant gender disparity is observed, with male users generating 62% of system alerts compared to 38% for female users. This pattern suggests a potentially higher rate of system interaction or usage among male users. The data also indicates that users in the 21-30 age bracket are the most likely to experience multiple, simultaneous battery alerts.

Figure 1: Alert Distribution by Gender & Year

The SBMS was notably effective in early fault detection, allowing timely interventions that averted critical battery failures. This is consistent with findings from other IoT-enabled EV battery management solutions. Seasonal trends in alert reports, with peaks during summer months, emphasize the impact of ambient temperature on battery degradation, consistent with studies highlighting thermal management as vital for battery longevity.

User demographic analysis showed that younger riders (21–40 years) experienced higher alert frequencies, possibly reflecting more aggressive riding behaviour or usage intensity. The gender distribution indicated higher system engagement and alerts among males, likely correlating with higher usage sage rates. These insights are important for tailoring maintenance and alert protocols to

user profiles. However, the absence of comprehensive demographic data limits definitive conclusions and warrants further investigation.

The study underscores the value of continuous monitoring in enhancing battery safety, efficiency, and lifespan, critical for the wider adoption of electric two-wheelers in regions with varied environmental and socioeconomic challenges. Future research should explore integrating advanced analytics and machine learning algorithms to further improve predictive capabilities and user experience.

In conclusion, the Smart Battery Monitoring System for EV Two Wheelers demonstrated robust performance in early detection of battery health issues, contributing to improved safety and reduced downtime. Strengthening such technologies will be vital in supporting sustainable urban transportation and accelerating electric mobility adoption.

CONCLUSION

The Smart Battery Monitoring System significantly enhances the safety, reliability, and efficiency of electric two-wheelers by providing real-time monitoring of critical battery parameters. It plays a vital role in early detection of battery faults and and help prevent breakdowns, contributing to extended battery lifespan and improved vehicle performance. Seasonal and usage related variations highlight the importance of adaptive monitoring strategies. Continued development and deployment of such smart monitoring technologies are essential to support the growing adoption of electric two-wheelers and to promote sustainable urban mobility

Declaration by Authors
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