

Design and Implement of Li-Ion Batteries Releasable Capacity Estimation with Neural Networks on Intelligent IOT Micro controllers

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Abstract: Lithium-ion batteries are extensively used in electric vehicles, renewable energy systems, and portable electronic devices due to their high energy density and efficiency. However, their performance and overall health degrade over time as a result of factors such as temperature fluctuations, humidity exposure, repeated charging–discharging cycles, and varying load conditions. Traditional battery monitoring techniques are primarily threshold-based, which often leads to inaccurate predictions under dynamic and real-world operating environments.

This project presents an IoT-based intelligent battery condition prediction system utilizing an ESP8266 microcontroller integrated with a Support Vector Machine (SVM) machine learning algorithm. Various sensors, including voltage, current, temperature, and humidity sensors, are employed to continuously monitor key battery parameters. The collected data is transmitted and stored using IoT technology and further processed using Python-based machine learning models.

The trained SVM model effectively classifies battery conditions, enabling efficient battery health and performance monitoring. This approach enhances prediction accuracy, thereby improving the safety, reliability, and lifespan of lithium-ion batteries. The system can also provide early warnings for potential battery failures, reducing maintenance costs and preventing unexpected breakdowns. Additionally, the integration of cloud-based storage allows remote access and analysis of battery data in real time. The proposed system is scalable and can be adapted for large-scale industrial and automotive applications. Overall, it supports smarter energy management and contributes to sustainable and efficient battery utilization.

I. INTRODUCTION

The increasing demand for efficient energy storage systems has made lithium-ion batteries a critical component in modern applications such as electric vehicles, renewable energy systems, and portable electronics. Accurate estimation of the releasable capacity of lithium-ion batteries is essential for ensuring optimal performance, safety, and longevity. Releasable capacity refers to the actual amount of energy that a battery can deliver under specific operating conditions, which gradually declines due to aging, environmental factors, and usage patterns. Traditional methods for estimating battery capacity rely on mathematical models and threshold-based techniques, which often fail to provide accurate results under dynamic and real-time conditions. These limitations highlight the need for more intelligent and adaptive approaches. In recent years, neural networks, a subset of machine learning, have gained significant attention for their ability to model complex nonlinear relationships and improve prediction accuracy.

This project focuses on the design and implementation of a lithium-ion battery releasable capacity estimation system using neural networks integrated with intelligent IoT microcontrollers. The system utilizes sensors to collect real-time battery parameters such as voltage, current, and temperature, which are processed using embedded machine learning models. By leveraging IoT technology, the system enables continuous monitoring, data transmission, and remote analysis. Furthermore, the use of intelligent IoT microcontrollers allows on-device processing, reducing latency and dependence on external computing systems. The neural network model is trained using historical battery data to recognize patterns and predict capacity degradation accurately. This system can adapt to varying operating conditions, making it more reliable than conventional methods. Additionally, real-time alerts and predictive insights help in preventing battery failures and optimizing maintenance schedules.

This approach enhances prediction accuracy, supports proactive maintenance, and improves overall battery management. The proposed system is scalable, cost-effective, and suitable for both small-scale and large-scale applications, contributing to smarter energy utilization and sustainable technological development.

II. LITERATURE REVIEW

Lithium-ion battery capacity estimation has been widely studied due to its importance in improving battery performance, safety, and lifespan. Earlier research mainly focused on model-based and threshold-based methods, which often lack accuracy

under dynamic operating conditions and require complex calculations. These methods are also sensitive to parameter variations and aging effects, which reduce their reliability over time.

To overcome these challenges, machine learning techniques such as neural networks have been introduced for better prediction of battery behavior. Neural networks can effectively capture nonlinear relationships between battery parameters like voltage, current, temperature, and state of charge, resulting in improved estimation accuracy. Compared to traditional approaches, these methods provide better adaptability and require less manual modeling effort.

These approaches improve prediction performance by considering historical data patterns and battery degradation trends over time.

Recent advancements include the integration of IoT technology for continuous battery monitoring. IoT-based systems enable real-time data collection, remote access, cloud storage, and efficient data analysis. This allows users to monitor battery health from anywhere and supports predictive maintenance strategies.

Some research has focused on hybrid models that combine machine learning with traditional techniques to further enhance accuracy and robustness. Additionally, feature extraction and data preprocessing methods have been improved to reduce noise and enhance model performance.

However, most existing systems are computationally intensive and are typically implemented on high-performance systems rather than embedded platforms. This limits their applicability in real-time and low-power environments. There is a growing need for lightweight and efficient models that can run on IoT microcontrollers with limited memory and processing power.

Furthermore, challenges such as data scarcity, varying environmental conditions, and battery aging behavior still affect prediction accuracy.

III. METHODOLOGY

The proposed system is designed to estimate the releasable capacity of lithium-ion batteries using neural networks integrated with intelligent IoT microcontrollers. The methodology consists of the following steps:

Initially, sensors are connected to the battery to continuously measure key parameters such as voltage, current, and temperature. These sensors collect real-time data during charging and discharging cycles. The collected data is then processed and transmitted using an IoT-enabled microcontroller (such as ESP8266) to a cloud or local storage system.

In the next stage, the acquired data is preprocessed using Python. This includes data cleaning, normalization, and feature selection to improve the quality of input data. The processed dataset is then used to train a neural network model, which learns the relationship between battery parameters and releasable capacity.

After training, the neural network model is deployed either on the microcontroller or integrated with the IoT system for real-time prediction. The system continuously analyzes incoming sensor data and estimates the battery's releasable capacity accurately.

Finally, the predicted results are displayed through a user interface or dashboard, allowing users to monitor battery health and performance in real time. The system can also generate alerts when abnormal conditions or capacity degradation is detected.

IV. MODELING AND ANALYSIS

The modeling and analysis of the proposed system focus on accurately estimating the releasable capacity of lithium-ion batteries using neural networks integrated with IoT microcontrollers. Initially, real-time data such as voltage, current, temperature, and charge–discharge cycles are collected using sensors connected to an ESP8266 microcontroller. This data is transmitted through IoT for storage and further processing. The collected raw data is then preprocessed by removing noise, handling missing values, and normalizing the inputs to ensure consistency and improve model performance.

1. Data Collection

- The first step in the system involves collecting battery data using sensors integrated with an IoT microcontroller such as ESP8266.
- Key parameters measured include voltage, current, temperature, and charge–discharge cycles, as these directly affect battery performance and releasable capacity.
- Data is collected continuously in real time during battery operation under different load conditions.
- The IoT module transmits this data to a cloud platform or local storage system for further processing and analysis.
- Continuous data collection ensures that the system captures dynamic variations in battery behavior.

2. Data Preprocessing

- The raw data collected from sensors may contain noise, missing values, or inconsistencies due to environmental conditions or sensor errors.
- Data cleaning techniques are applied to remove unwanted noise and handle missing values effectively.
- Normalization or scaling is performed to bring all input parameters into a common range, improving model performance.
- Feature selection is carried out to identify the most relevant parameters influencing battery capacity.
- This step ensures that high-quality data is used for training the neural network model.

3. System Modelling

- The system is modeled using a neural network due to its ability to capture complex and nonlinear relationships between battery parameters and releasable capacity.
- The neural network architecture consists of three main layers: input layer, hidden layers, and output layer.
- The input layer receives processed parameters such as voltage, current, and temperature.
- Hidden layers perform computations using weights, biases, and activation functions to learn patterns in the data.
- The output layer provides the predicted releasable capacity of the battery.
- The model structure is designed to balance accuracy and computational efficiency for implementation on IoT microcontrollers.

4. Model Training

- The neural network model is trained using historical battery data that includes both input parameters and corresponding actual capacity values.
- During training, the model adjusts its weights using optimization algorithms such as gradient descent to minimize prediction error.
- Multiple training iterations (epochs) are performed to improve learning accuracy.
- The dataset is divided into training and testing sets to validate model performance.
- Hyperparameters such as learning rate, number of neurons, and number of layers are tuned to achieve optimal results.
- This step ensures that the model can generalize well to new and unseen data.

5. Performance Analysis

- After training, the model is evaluated using performance metrics such as Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and accuracy.
- These metrics help in measuring how close the predicted capacity values are to actual values.
- Graphical analysis is performed to compare predicted and actual results over time.
- Error analysis helps in identifying limitations and improving the model further.
- The model is refined iteratively to achieve higher prediction accuracy and stability.

6. Real-Time Implementation

- The trained neural network model is deployed on the IoT platform or embedded within the microcontroller.
- Real-time sensor data is continuously fed into the model for instant prediction of battery capacity.
- The system operates efficiently under varying environmental and load conditions.
- Edge computing capabilities of the microcontroller allow faster processing and reduced latency.
- This enables real-time decision-making and monitoring without heavy dependence on external systems.

7. Result Visualization

- The predicted battery capacity and other parameters are displayed through a user-friendly interface such as a web dashboard or mobile application.
- Graphs and charts are used to visualize battery performance trends over time.
- Users can easily monitor battery health and identify degradation patterns.
- Alerts and notifications are generated when abnormal conditions such as overheating or low capacity are detected.
- Visualization improves user understanding and supports effective battery management.

8. Analysis Outcome

- The neural network-based model demonstrates higher accuracy compared to traditional threshold-based and model-based methods.
- The system effectively adapts to dynamic operating conditions and varying battery behavior.
- Real-time monitoring and prediction enhance battery safety and reliability.
- The approach reduces maintenance costs by enabling predictive maintenance strategies.

V.RESULTS AND DISCUSSION

The proposed Li-Ion Batteries Releasable Capacity Estimation with Neural Networks on Intelligent IoT Microcontrollers demonstrate significant improvements in battery performance, safety, and reliability for electric vehicles. The system successfully monitors key parameters such as voltage, current, state of charge (SOC), state of discharge (SOD), and temperature in real-time with high accuracy. Continuous data acquisition and cloud integration enable remote monitoring and effective data analysis, ensuring timely detection of abnormal conditions. Automated alerts help prevent critical failures such as overcharging, deep discharge, and overheating, thereby enhancing battery lifespan. The incorporation of machine learning techniques allows accurate prediction of battery efficiency and health trends based on historical data. Experimental results show improved energy utilization and optimized charging cycles, leading to increased overall efficiency.

V. CONCLUSION

The Li-Ion Batteries Releasable Capacity Estimation with Neural Networks on Intelligent IoT Microcontrollers for electric vehicles provides an efficient and reliable solution for monitoring and managing battery performance. By integrating real-time sensing of voltage, current, temperature, state of charge (SOC), and state of discharge (SOD), the system ensures safe and optimal battery operation. The use of IoT technology enables continuous data transmission to the cloud, allowing remote monitoring and easy accessibility of battery information. The implementation of automated alerts helps in preventing critical issues such as overheating, overcharging, and deep discharge. Furthermore, the incorporation of machine learning enhances the system's capability to predict battery efficiency and health, enabling predictive maintenance. The proposed system improves battery lifespan, reduces maintenance costs, and enhances overall energy efficiency. It is scalable and can be applied to various domains including electric vehicles and renewable energy systems. Overall, the system contributes to improved safety, performance, and intelligent energy management, making it a valuable solution for modern battery applications

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