Industry Mathematics Project Report:

Real-time Prediction of Battery Degradation Status
Using Artificial Intelligence Techniques

Seoyoung Oh

Today, lithium-ion batteries are widely used in various fields such as Electric Vehicles and Energy Storage Systems. Consequently, the need for effective State of Health (SoH) prediction algorithms for battery charge status and lifespan forecasting has increased significantly.

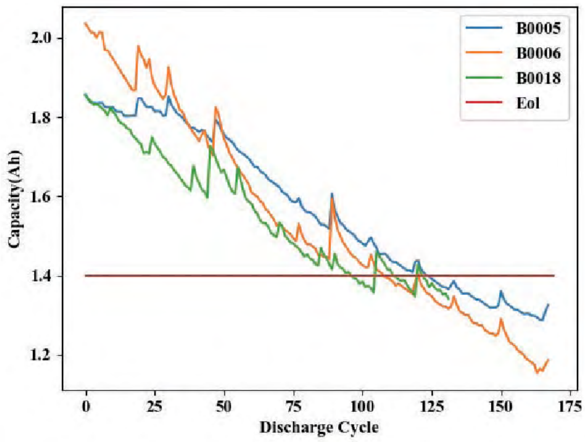
SoH refers to the state of battery aging, which indicates the capacity to store electricity. When a Cycle is defined as the number of battery discharges, let's denote $\mathrm{Q_m}$ as the discharge charge at the m-th discharge cycle and $\mathrm{Q_{nom}}$ as the rated charge value provided during battery manufacturing. Therefore, the SoH can be expressed as:

$$\mathrm{SoH} = \frac{Q_m}{Q_{nom}}.$$

SoH is calculated using the Capacity Method by leveraging data from NASA's Prognostics Center of Excellence (PCoE). A single value is computed for each Discharge Cycle, resulting in a value between 0 and 1. Generally, as the number of Cycles increases, the SoH decreases. The rated capacity of SoH at the time of battery manufacture is 100%, and it is typically used until the SoH decreases to around 60% to 70%.

We aim to conduct a simulation to predict SoH trends based on the number of Discharge Cycles. Given time series data from the first to the N-th Discharge Cycle, we will predict the SoH and Capacity for the (N+1)-th Discharge Cycle, as well as the number of future Discharge Cycles that can be utilized.

First, we will use a simple linear regression model for the prediction simulation. Linear regression is a regression analysis technique that models the linear correlation between a dependent variable and one or more independent variables.



The figure indicates the capacity and failure threshold of lithium-ion batteries. From this, we can infer that the actual data roughly resembles a linear pattern, and we intend to utilize linear regression to predict the SoH and Capacity.

The data we have consists of time series measurements of lithium-ion battery charging and discharging. Considering the characteristics of the data, we plan to use a deep learning model known as RNN (Recurrent Neural Network) that utilizes the temporal properties of time series data. Basic neural network structures typically have values that pass through the activation function in the hidden layers and only flow to the output layer.

However, RNNs have the characteristic of sending the results derived from the activation function in the hidden layer not only to the output layer but also back as input for the next calculation in the hidden layer nodes. In simple terms, this means that at each time point, the model performs recursive activity by using the value from the immediately preceding time point as its own input. Through this structure, where past information continuously influences future predictions, we aim to understand the time series characteristics of the data.

RNN has the disadvantage of struggling to propagate learned information when the distance between relevant information and the point where that information is used is far apart. In predicting data at the last time step, it may be necessary to utilize information from a long time ago, which is why LSTM (Long Short-Term Memory), capable of performing learning with long dependence periods, will also be employed for prediction.

LSTM learns what information to discard and what to carry forward through several gate structures, storing this information in the cell state. Additionally, decisions regarding the output are made based on this cell state. Using the aforementioned linear regression, RNN, and LSTM, the study will predict SOH and capacity, analyze the results, and explore what factors can be considered as important characteristics for predicting battery lifespan.

References

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