Battery States Monitoring Using Deep learning and Ultrasonic sensors

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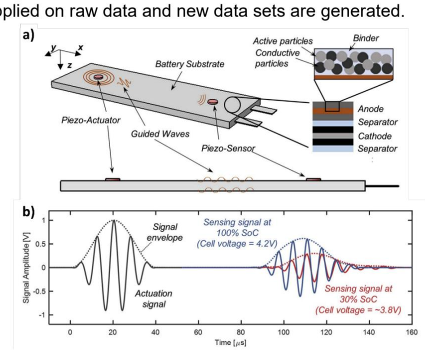
Introduction

state-of-the-art BMS technology relies only on the terminal voltage measurement to estimate both SoC and SoH, which alone is insufficient for accurately determining the two states. Recently, active ultrasonic guided waves propagation characteristics have been demonstrated as a potentially strong, on-board alternative method to probe the mechanical behavior of lithium-ion batteries. The main goal of this research is to develop a novel BMS framework where rich data available from ultrasonic guided wave sensors, data mining and deep learning will serve as powerful tools for modeling and predicting the battery condition under complexity and uncertainty.

The sensor data are collected and stored in mat format. Sensors data are collected at different state of charge of batteries and there are nine paths of sensor data at varying frequency. The sampling frequency of the sensor is 48 $\times 10^{-6}$ Hz, with sampling points of 4000. At different states of the battery, the output signals of the sensors are different. Therefore, each samples have a dimension of 4000 × 9. And number of the samples are 1500. Data are down sampled to the size of 400 × 9. Fourier Transform are applied on raw data and new data sets are generated.



Methods

Input Layer

Inputs have dimension of 400 × 9.

Model Structure

Fully connected layer

Three hidden layer, 50 neurons in first hidden layer, 20 in second layer, 3 in last hidden layer

Relu activation layer

Convolutional neural network

Two Layer of Convolution 2D layer followed by Batch normalization layer and Relu layer.

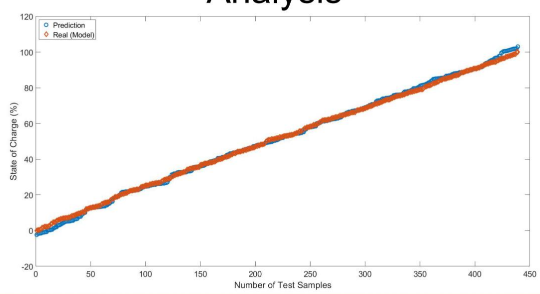
One fully connected layer

Regression output layer

Loss function:

$$MSE = \frac{1}{N}\sum_{i=1}^{n}(y_{true} - y_{pred})^2$$

Analysis

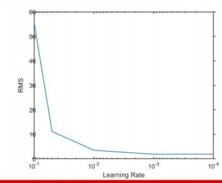


Analysis

The collected sensors data shows the nonlinear properties with respect to the state of charge of batteries. After applying the deep learning methods on the sensor data, the figure shows that deep learning methods successfully predict the state of charge. The RMS of using fully connected layer is 1.88%. And the RMS of using convolution neural network is around 3%. That may conclude that in this application and type of input data, it's not suitable to treat the input as "image" while using convolutional neural network. After wavelet transform or other signal processing, convolutional neural network may be useful in this application.

After applying the Fourier Transform, with the same settings as raw data. The RMS of Fourier Transform is 4.2%, while the raw data is 2.3%. This might cause by after applying the Fourier Transform, some important features in the time domain data is lost.

Influence of learning rate on network performance is analyzed. In fully connected layer method, as learning rate increase, the RMS of validation sets is increasing.



Future work

In the project, raw data and Fourier transformed data are used as the inputs of the network. In the future, Wavelet Transform will the used to pre-process data.

More data need to be collected to do the estimation of not only the battery states but also battery health.