
一、背景

化石能源的劣势导致新能源的兴起。可充电电池作为储能技术被广泛应用，锂电池则是智慧城市、新能源汽车发展必不可少的一项技术。但其广泛应用的同带来了环境污染，电池老化等问题，对电池寿命预测可以提前应对这些问题还可以对电池二次回收，故电池寿命预测是非常有必要的。

Renewable energy technologies in Pakistan: Prospects and challenges
Wind energy development in Pakistan. Renewable and Sustainable Energy Reviews
Renewable Energy Resources: Basic Principles and Applications
Porous Carbon Composites for Next Generation Rechargeable Lithium Batteries
Recent progress of magnetic field application in lithium-based batteries
A review on artificial intelligence based load demand forecasting techniques for smart grid and buildings
An energy matching method for battery electric vehicle and hydrogen fuel cell vehicle based on source energy consumption rate
Traffic-constrained multiobjective planning of electric-vehicle charging stations
Optimization and model validation of operation control strategies for a novel dual-motor coupling-propulsion pure electric vehicle

锂电池寿命预测方法主要分为三大类，其中，数据驱动的方法因其独特的优势（不需要了解电池内部化学反应，不需要基础的物理化学知识）作为当今热点研究方法。在测量时的不稳定性、环境变换、人为干扰等一系列因素导致电池数据集含有噪声。如果能在考虑噪声影响的同时准确的对电池寿命进行预测，就可以提高模型的稳定性，也能更好的拟合现实中电池衰退。

Predicting the State of Charge and Health of Batteries using Data-Driven Machine Learning
Machine learning pipeline for battery state of health estimation
Data-driven prediction of battery cycle life before capacity degradation
Lithium-ion battery cell degradation resulting from realistic vehicle and vehicle-to-grid utilization
Modeling and simulation of lithium-ion batteries from a systems engineering perspective
Critical review of the methods for monitoring of lithium-ion batteries in electric and hybrid vehicles
Identifying degradation patterns of lithium ion batteries from impedance

spectroscopy using machine learning

Data-driven prediction of battery cycle life before capacity degradation

Health diagnosis and remaining useful life prognostics of lithium-ion batteries using datadriven methods

Online identification of lithium-ion battery parameters based on an improved equivalent-circuit model and its implementation on battery state-of-power prediction

Characterization of high-power lithium-ion batteries by electrochemical impedance spectroscopy

Matthew J Daigle and Chetan Shrikant Kulkarni. Electrochemistry-based battery modeling for prognostics

Adaptation of an electrochemistry-based li-ion battery model to account for deterioration observed under randomized use. Technical report

Model based identification of aging parameters in lithium ion batteries

Data-driven prediction of battery cycle life before capacity degradation

Prognostics methods for battery health monitoring using a bayesian framework.

Prognostics in battery health management.

Battery health prognosis for electric vehicles using sample entropy and sparse bayesian predictive modeling

A support vector machine-based state-of-health estimation method for lithium-ion batteries under electric vehicle operation

Closed-loop optimization of fast-charging protocols for batteries with machine learning. Nature

LS/TLS 作为线性参数估计问题的经典解法，能够在测量数据含有噪声情况

下保持较高的预测精准度，是预测带噪声数据集的不二选择。

Detection of Abrupt Changes of Total Least Squares Models and Application in Fault Detection

in Recent Advances in Total Least Squares Techniques and Error-in-Variables Modeling

Frontiers in Applied Mathematics: The Total Least Squares Problem—Computational Aspects and Analysis. Philadelphia

Recent Advances in Total Least Squares Techniques and Errors-In-Variables Modeling

但在实际情况下，不同的电池数据集的噪声来源一般是不同的，造成了不同数据集的噪声分布不同，此时对 LS/TLS 进行改进以适应噪声分布不同的电池寿命预测问题。总结本文的改进。

二、算法主要流程

介绍研究问题的背景，样本所携带的噪声标准差不同，对每个样本进行加权以适应不同的标准差，对比最大化似然函数得到权值。则算法中存在模型系数、噪声标准差两个变量，使用 EM 算法思想通过循环迭代拟合噪声标准差，写出具体循环过程，算法流程，算法伪代码。

What is the expectation maximization algorithm?

Jing Song, G., Wen Wang, Q. On the weighted least-squares, the ordinary least-squares and the best linear unbiased estimators under a restricted growth curve model. Stat Papers 55, 375–392 (2014). <https://doi.org/10.1007/s00362-012-0483-9>

B. De Moor and J. Vandewalle, "A unifying theorem for linear and total linear least squares," in IEEE Transactions on Automatic Control, vol. 35, no. 5, pp. 563–566, May 1990, doi: 10.1109/9.53523.

三、结果分析

本文使用三个基于商用锂离子电池的公共数据集，三个数据集分别称为“数据集 1”、“数据集 2”和“数据集 3”，分别由 41 个、43 个和 40 个样本组成，虽然这些数据集总共提取了 20 个特征，但我们进一步根据领域专业知识手动选择 3 个重要特征的子集，具体含义见 table1，我们将三个数据集按照 9:1 划分之后合并作为训练集和测试集，每次实验随机打乱样本顺序，每次运行均独立随机生成训练和测试数据集。为每种方法报告 1000 个 RMSE 值的中位数，以便误差度量不会因随机波动而产生强烈偏差。

Data-driven prediction of battery cycle life before capacity degradation

如图 3 所示，我们设置了四种不同的噪声比例。图 a,b,c,d 是噪声水平增大的实验结果：(1) 随着噪声增大，TLS 和 OLS 效果明显变差，而改进的算法受噪声水平的影响不明显，具有较强的稳定性。(2) 结合 EM 思想改进的算法 (TLS_EM、

OLS_EM) 比传统算法 (TLS、OLS) 效果更佳,说明了改进的算法更能适应带有噪声的电池数据集。(3) TLS_EM 效果优于 OLS_EM, (TLS 效果也优于 OLS), 在所有测量值都收到噪声污染的情况下, TLS 比 LS 有更大的优势。

图 e,f,g,h 是训练集比例增大的实验结果:(1) 随着训练集占比增大,四种方法效果更好,有了更多的训练数据,模型预测能力提升。(2) 不论训练集比例大小,改进的算法优于传统算法,说明了融入 EM 思想的算法有效性。(3) 在绝大部分情况下(训练集占比大于 25%) TLS_EM 效果优于 OLS_EM,说明了 TLS_EM 比 OLS_EM 适用性更强。

图 4 展示了算法经过循环迭代噪声收敛过程。在算法迭代过程中,计算出的噪声分布不断逼近真实噪声。

四、总结

本文在建立线性模型计算电池的寿命时进行改进,对带有不同噪声分布的电池样本进行加权之后,使用 TLS/OLS 进行预测,经循环迭代能够在准确的计算出噪声分布的标准差的同时建立适应不同噪声分布的预测模型,进而对电池寿命进行预测。预测结果显示我们的方法有着更好的效果。