Assignment

Assignment: Battery State-of-Health (SOH) Estimation Using AI method

Assignment Objective:

Implement battery SOH estimation using the Oxford battery aging dataset.

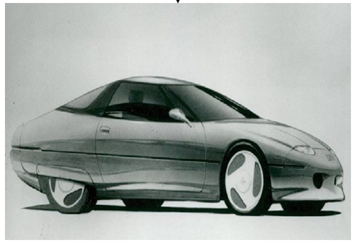
Course: SEEN6001B (Prof. Xiangyu Li)

TA: Shuo Zhang

Tutorial

The GM EV1 bring the electric vehicle to market.

1996

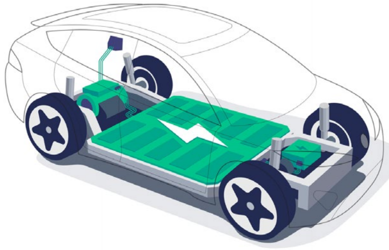


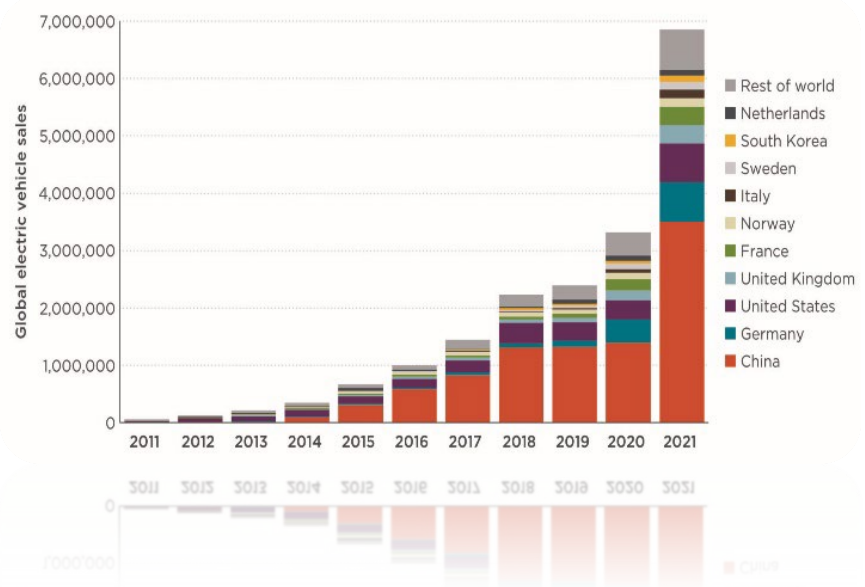
Tesla launched the Roadster

2017

BYD launches the Han EV.

2020





Big Capacity

Low Pollution

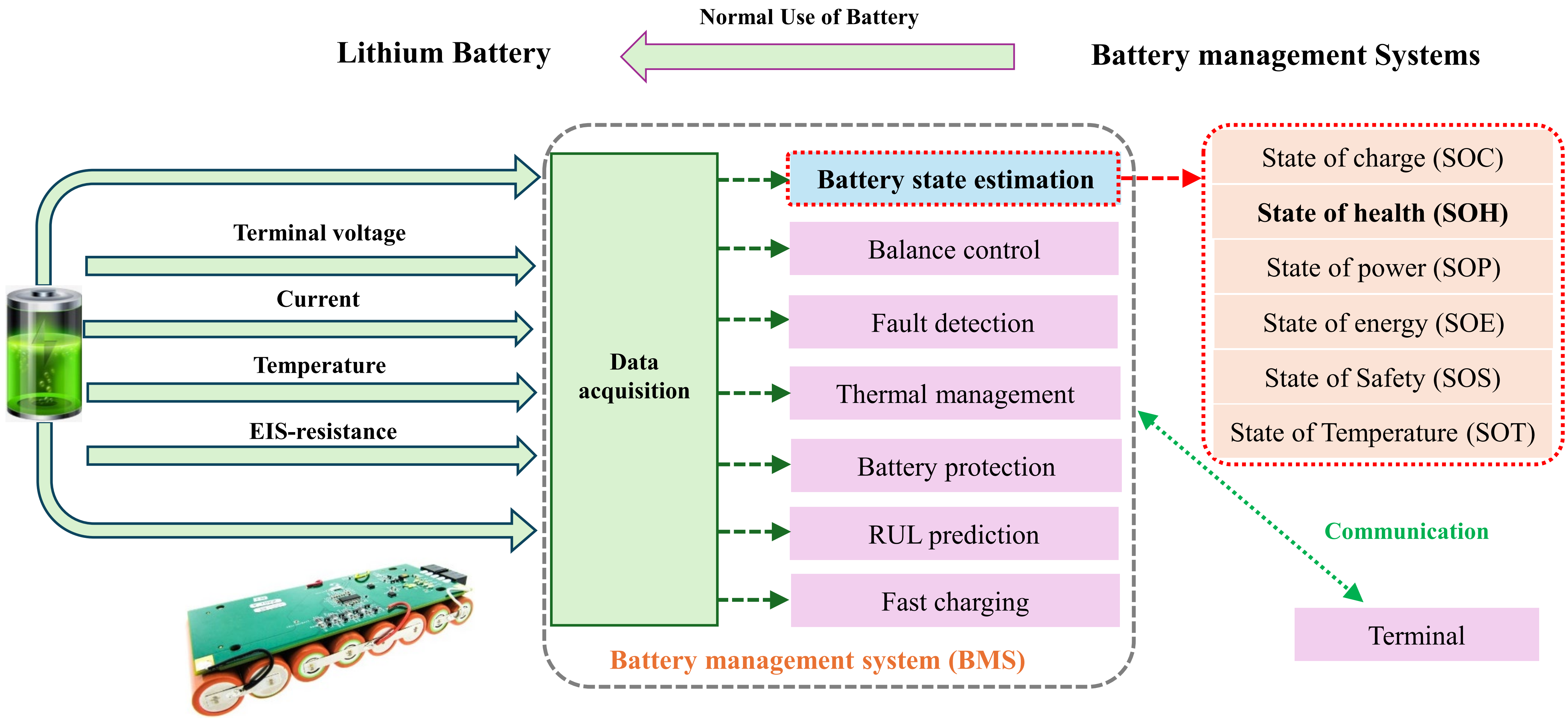
High Density

Long Cycle Lifetime

Small Size

Green Performance

Tutorial


Normal Use of Battery
Lithium Battery
Battery management Systems
Terminal voltage
Current
Temperature
EIS-resistance
Data acquisition
Battery state estimation
Balance control
Fault detection
Thermal management
Battery protection
RUL prediction
Fast charging
Battery management system (BMS)
State of charge (SOC)
State of health (SOH)
State of power (SOP)
State of energy (SOE)
State of Safety (SOS)
State of Temperature (SOT)
Communication
Terminal

Tutorial

1. What is SOH?

SOH refers to the health status of a battery relative to its ideal state when brand - new. It reflects the battery's ability to store and deliver energy, and how much its performance has degraded over time or usage.

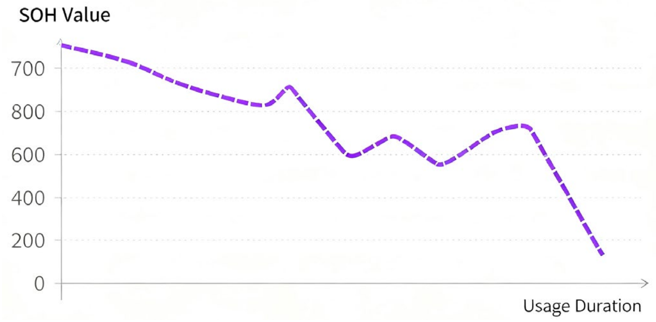
2. Why is SOH Important?

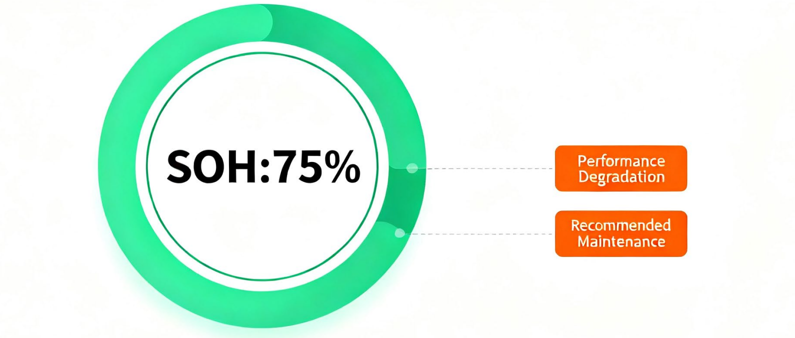
- It helps predict the remaining useful life of a battery.
- Enables timely maintenance or replacement to ensure system reliability (e.g., in electric vehicles, energy storage systems).
- Assists in estimating the battery's capacity, efficiency, and safety.

3. How is SOH Assessed?

Common methods include analyzing capacity fade, internal resistance increase, voltage characteristics changes (Incremental Capacity Analysis or Differential Voltage Analysis), and some closed-loop estimation algorithms.

Advanced techniques involve **AI algorithms to model degradation patterns.**





Tutorial

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Dataset Description -Oxford Battery Degradation Dataset：

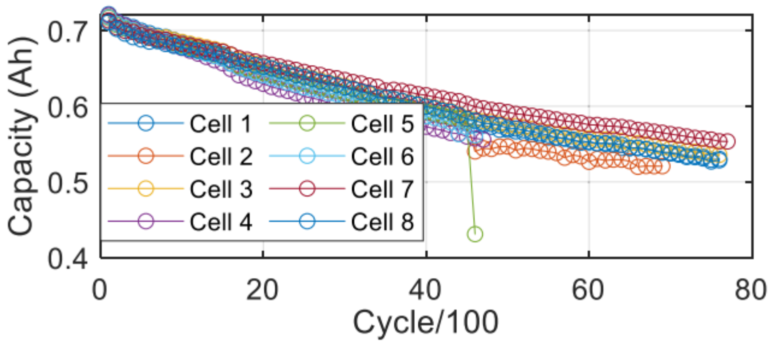


Figure. 1 Aging trajectories of Cell1–Cell8

Dataset Description：

1. The Oxford battery degradation dataset includes battery ageing data collected from eight cells with capacity of 740 mAh at 40°C.
2. They are labeled as cell 1 to cell 8 respectively. The negative electrode material of the Kokam pouch cells is graphite, the positive electrode material is a blend of lithium cobalt oxide (LCO) and lithium nickel cobalt oxide (NCO).
3. The eight batteries are subjected to a constant-current and then constant-voltage charging profile up to 4.2 V, followed by a variance discharge current rate from the urban Artemis derived profile process down to 2.7 V.

Access Document

Files: ExampleDC_C1.mat
Oxford_Battery_Degradation_Dataset_1.mat
Readme.txt

Authors/Creators

Specifications of the Oxford degradation dataset.

Dataset parameters	Specifications
Battery chemistry	$LiCoO_2/LiNiMnCoO_2$
Temperature	40 °C
Capacity	0.74 Ah
Charging	1.48A CC
Discharging	Dynamic Artemis profile
EOL	80%

Link： Oxford Battery Degradation Dataset 1 - ORA - Oxford University Research Archive

Data Preprocessing -Oxford Battery Degradation Dataset： (MATLAB/Python)

工作区

名称	值	字节
Cell1	1x1 struct	73868816
Cell2	1x1 struct	67644040
Cell3	1x1 struct	71182944
Cell4	1x1 struct	44768280
Cell5	1x1 struct	44622928
Cell6	1x1 struct	44435152
Cell7	1x1 struct	73000648
Cell8	1x1 struct	70760384

Cell1 | Cell1.cyc0000 | Cell1.cyc

1x1 struct 包含 78 个字段

字段	值
cyc0000	1x1 struct
cyc0100	1x1 struct
cyc0200	1x1 struct
cyc0300	1x1 struct
cyc0400	1x1 struct
cyc0500	1x1 struct
cyc0600	1x1 struct
cyc0700	1x1 struct
cyc0800	1x1 struct
cyc0900	1x1 struct

所选内容

Cell1 | Cell1.cyc0000

Cell1.cyc0000

字段	值
C1ch	1x1 struct
C1dc	1x1 struct
OCVch	1x1 struct
OCVdc	1x1 struct

Cell1.cyc0000.C1ch

字段	值
t	3510x1 double
v	3510x1 double
q	3510x1 double
T	3510x1 double

Select Battery Charging process (C1ch)

Charging current, voltage, capacity, temperature

Cell1.cyc0000.C1ch.q

	1	2
3505	723.1581	
3506	723.3644	
3507	723.5707	
3508	723.7769	
3509	723.9832	
3510	724.1209	
3511		

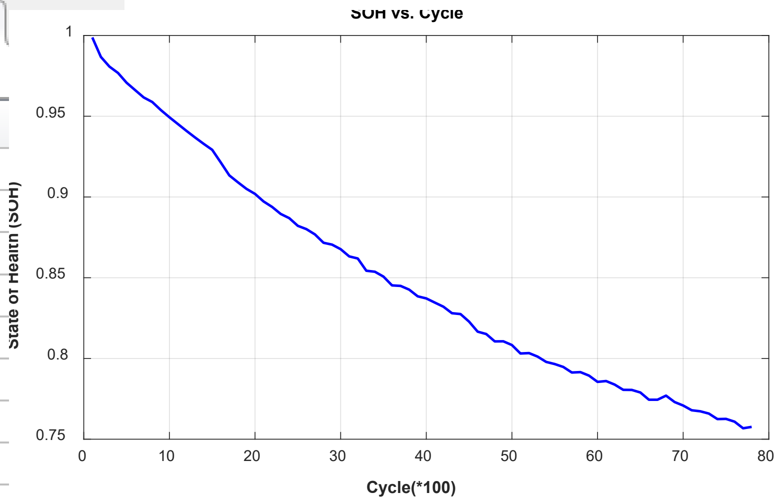
```
clc
clear all
close all
load Oxford_Battery_Degradation_Dataset_1
cycles=struct2cell(Cell1);
%绘制ICA曲线以及提取ICA峰值特征Peak_HF
L=20;%差分步长
for i=1:length(cycles)
        u=cycles{i}.C1ch.v;%电压
        Q=cycles{i}.C1ch.q/1000;%电量q，单位变成Ah
        Capacity(i)=Q(end);
```

The last point in the charging process

Capacity

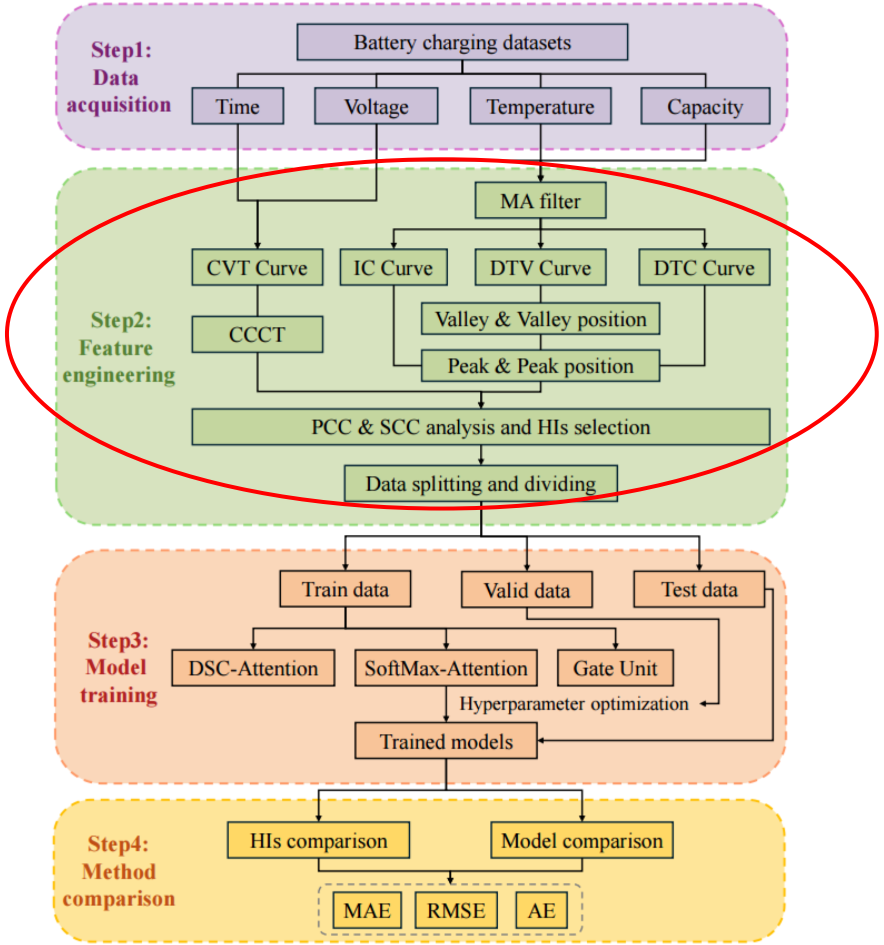
78x1 double

	1
1	0.7241
2	0.7145
3	0.7099
4	0.7070
5	0.7022
6	0.6988
7	0.6955
8	0.6917
9	0.6876



Tutorial

Feature Selection / Engineering



Feature (**For different electrochemical systems, appropriate features should be selected accordingly**):

1. Constant current charge time within the charge segment (CCCT)
2. Constant current discharge time within the discharge segment
3. Peak value of the IC curve within the charge segment (IC Curve)
4. Differential temperature voltammetry curve (DTV)

-
-
-

Tutorial

Feature Selection / Engineering   IC Curve Peak Point -SOH

```
for j=1:length(u)-L
    dQ(j+L)=(Q(j+L)-Q(j));
    dv(j+L)=(u(j+L)-u(j));
end
dQ=dQ(L+1:end)';
dv=dv(L+1:end)';
dQ_dV=dQ./dv;
u=u(L+1:length(u));
```

L-Difference step size

```
raw_dQ_dV = dQ_dV;
alpha = 0.009;       % FILTER
filtered_dQ_dV = zeros(size(raw_dQ_dV));
filtered_dQ_dV(1) = raw_dQ_dV(1);  %
for k = 2:length(raw_dQ_dV)
    filtered_dQ_dV(k) = alpha * raw_dQ_dV(k) +...
    (1 - alpha) * filtered_dQ_dV(k-1);
end
dQ_dV = filtered_dQ_dV;
```

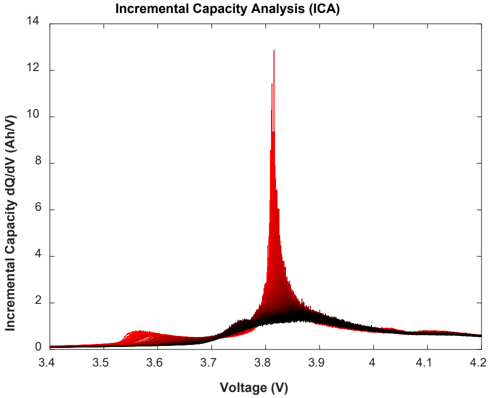
First-order filter process

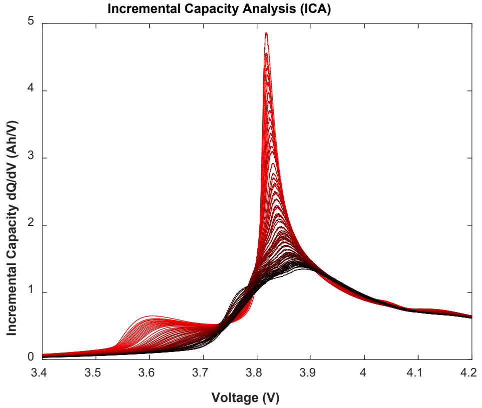
$$Q = \int_{\tau=1}^{t} I d\tau \qquad \frac{dQ}{dV} = \frac{I \cdot dt}{dV} = I \cdot \frac{dt}{dV}$$

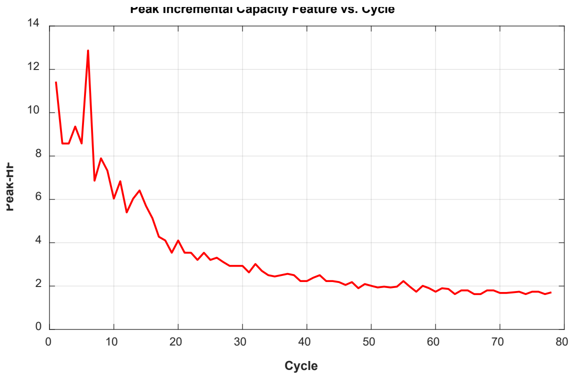
$$V = f(Q),\ Q = f^{-1}(V)$$

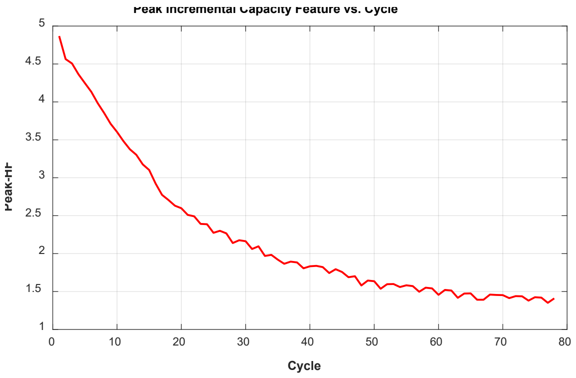
```
%ICA PEAK POINT
Peak_HF(i)=max(dQ_dV);
```

The differencing process and sensor noise introduce additional noise, which is detrimental to the peak extraction of signals in Independent Component Analysis (ICA). – lower P value









Filtered- Pearson Correlation Coefficient=0.9+

Model Design and Training the Model

This stage is about **choosing the right AI architecture** and deciding how the model will process features to predict SOH.

Model Structure Decisions

•Input layer: selected features (e.g., IC peak values/other features).
•Hidden layers: number of layers, neurons per layer, activation functions.
•Output layer: predicted **SOH value.**

Optimization Process

•Define a **loss function** (e.g., Mean Squared Error, Mean Absolute Error).
•Choose an **optimizer** (e.g., SGD, Adam) to update model weights.
•Adjust hyperparameters (learning rate, batch size, regularization).(You can use some optimization algorithm to get them)

Data Splitting Strategy

1.Data-wise split

1. About **70% of the data** is used for training.
2. About **30% of the data** is used for validation.

2.Cell-wise Split

1. To test generalization across different cells, the dataset is divided at the **cell level**:
   1. **6 cells** are used for training.
   2. **2 cells** are held out for validation/testing.

Tutorial

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Case 1 IC Curve Peak Point –SOH (SVR model)

```
clc
clear all
close all

%% Data Preparation
% Training set: Cell1~Cell6
train_set = [];
for i = 1:6
    load(['Cell' num2str(i) '_Peak_HF.mat']);
    load(['Cell' num2str(i) '_SOH.mat']);
    temp_train = [Peak_HF; SOH];
    train_set = [train_set temp_train];
end

% Test set: Cell7 and Cell8
load('Cell7_Peak_HF.mat'); load('Cell7_SOH.mat');
test_Cell7_x = Peak_HF; test_Cell7_y = SOH;

load('Cell8_Peak_HF.mat'); load('Cell8_SOH.mat');
test_Cell8_x = Peak_HF; test_Cell8_y = SOH;
```

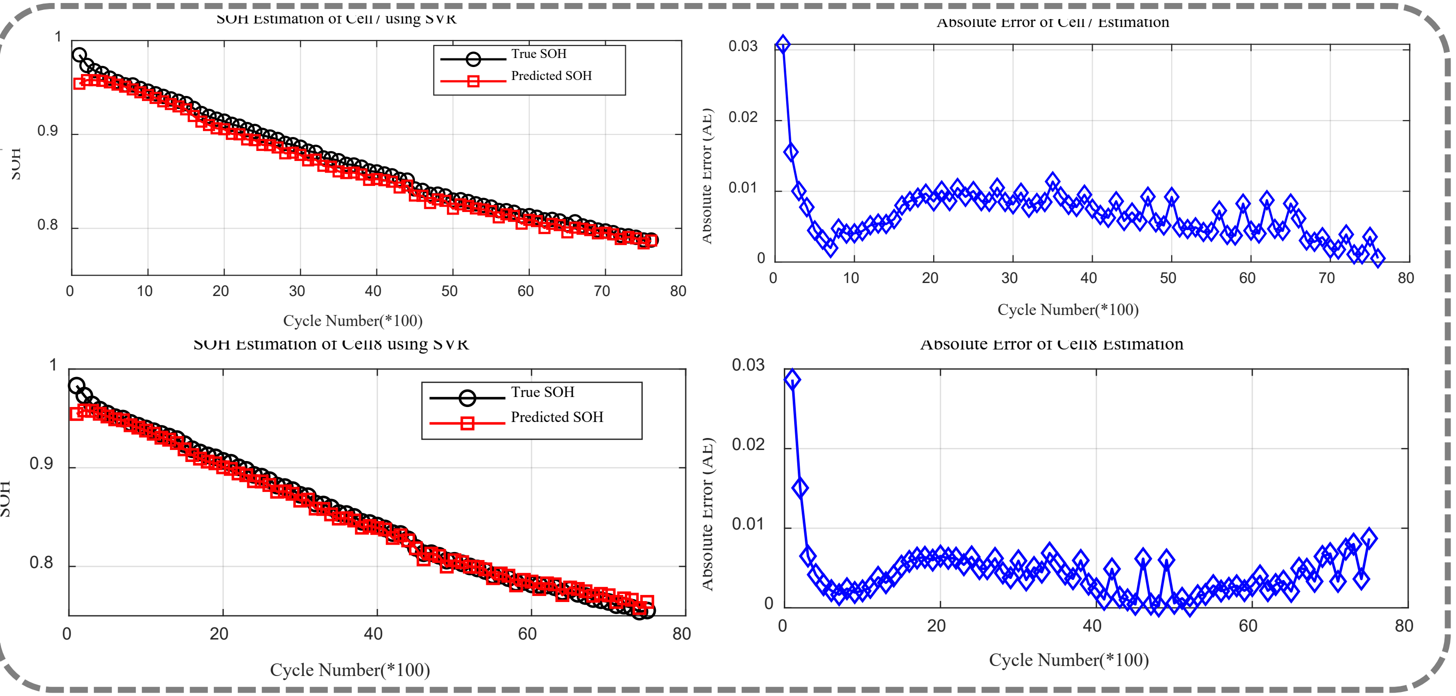
Data input

```
%% Normalization
Mx = max(train_set(1,:)); mx = min(train_set(1,:));
My = max(train_set(2,:)); my = min(train_set(2,:));

% Normalize training data
x = (train_set(1,:) - mx) / (Mx - mx);
y = (train_set(2,:) - my) / (My - my);

% Normalize test data
xt_Cell7 = (test_Cell7_x - mx) / (Mx - mx);
xt_Cell8 = (test_Cell8_x - mx) / (Mx - mx);

%% Support Vector Regression (SVR)
% Using RBF kernel
svr_model = fitrsvm(x', y', 'KernelFunction','rbf','Standardize',true,'BoxConstraint',1);
```

SVR model

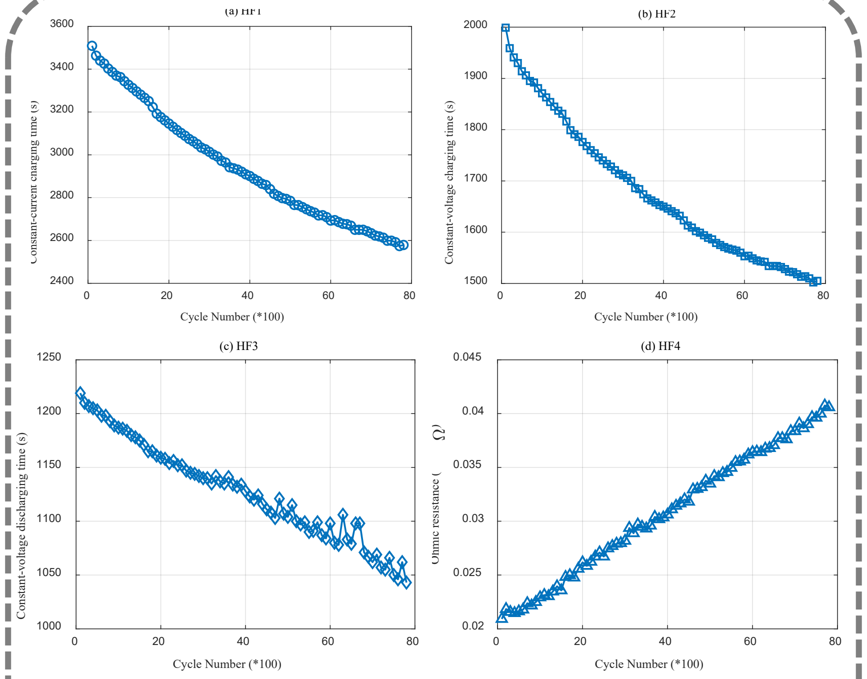
```
%% Prediction for Cell7
y_pre7 = predict(svr_model, xt_Cell7');
y_pre7 = y_pre7*(My-my) + my; % Denormalize

% Plot SOH estimation
figure
plot(test_Cell7_y,'k-o','LineWidth',1.5); hold on
plot(y_pre7,'r-s','LineWidth',1.5);
xlabel('Cycle Number','FontName','Times New Roman');
ylabel('SOH','FontName','Times New Roman');
legend('True SOH','Predicted SOH','Location','best','FontName','Times New Roman');
title('SOH Estimation of Cell7 using SVR','FontName','Times New Roman');
grid on

% Plot Absolute Error
figure
plot(abs(test_Cell7_y - y_pre7),'b-d','LineWidth',1.5);
xlabel('Cycle Number','FontName','Times New Roman');
ylabel('Absolute Error (AE)','FontName','Times New Roman');
title('Absolute Error of Cell7 Estimation','FontName','Times New Roman');
grid on
```

Predict results



Tutorial

Case 2 Four features input –SOH (LSTM model)

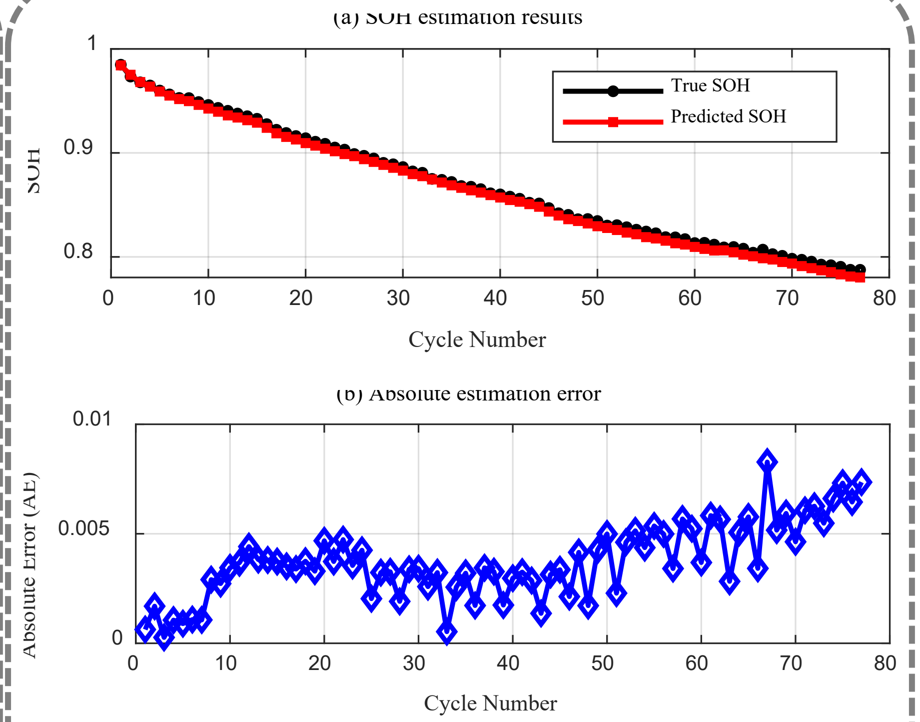


1. Constant Current Charging Time
2. Constant Voltage Charging Time
3. Constant Voltage Discharging Time
4. Ohmic/Internal Resistance

As the battery ages, the charging and discharging times in certain segments tend to change.

```
% 定义网络结构
Output_size = 1;
Input_size = 4;
numHiddenUnits = 100; %LSTM节点个数
layers = [ ...
    sequenceInputLayer(Input_size)
    lstmLayer(numHiddenUnits,'OutputMode','sequence')
    dropoutLayer(0.1)
    fullyConnectedLayer(50)
    reluLayer
    fullyConnectedLayer(Output_size)
    regressionLayer];

maxEpochs = 200;%训练次数
miniBatchSize = 3;

options = trainingOptions('adam', ...
    'MaxEpochs',maxEpochs, ...
    'MiniBatchSize',miniBatchSize, ...
    'InitialLearnRate',0.005, ...
    'LearnRateSchedule','piecewise', ...
    'LearnRateDropPeriod',100, ...
    'LearnRateDropFactor',0.2, ...
    'GradientThreshold',1, ...
    'Plots','training-progress',...
    'Verbose',0);

% 训练
net = trainNetwork(norm_train_X,norm_train_Y,layers,options);
save('LSTM_net','net')%保存训练好的网络
```

LSTM modelling



Predict results

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AI-Based SOH Estimation Report for Oxford Battery Dataset

Suggested Report Structure:

1. Introduction
2. Data Description
3. Feature Selection / Engineering
4. AI Model Selection and Model Description
5. AI Training and Validation Process
6. Validation Results (e.g., RMSE, MAE, Max Error, etc.)
7. Conclusion

The score is determined by two factors:

1. Achieve the battery SOH estimation using AI method.
2. Overall completeness of the report.

1. Data Splitting Strategy **Any strategy**

Data-wise split

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Cell-wise Split

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2. Language: MATLAB/Python

3. Upload Zip: Report +Coding

Link: Oxford Battery Degradation Dataset 1 - ORA - Oxford University Research Archive

Tutorial

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