Li-Ion Battery SoC Estimation Using a Bayesian Tracker

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Agenda

- Review: Battery Modeling & SoC Estimation
- Electro-chemical model and its governing equations
- Potter tracker for SoC estimation
- Computer experiments
- Summary

Batteries

- Batteries chemically store electrical energy
- 3 parts: Anode (-ve), Cathode (+ve) & Electrolyte
- Electrochemical potential (voltage) is the result of redox (Reduction-Oxidation)
- Current is the product of ion transfer

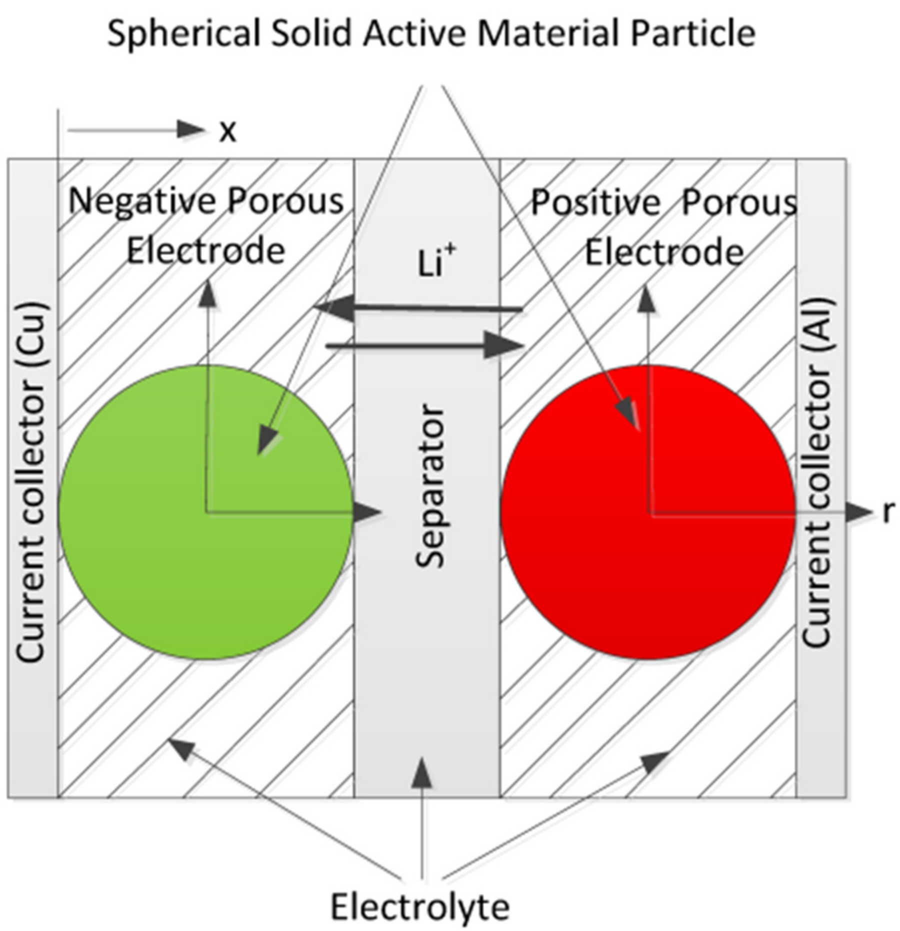
Li-ion Batteries

- Overall Chemical reaction
  - $Li_xC + Li_{(1-x)}M_yO_z \leftrightarrows C + LiM_yO_z$ (M can be Mn, Co or Ni)
- Rocking chair
- Pros: No memory, high power-to volume, low self discharge
- Cons: Safety
- Battery Management System (BMS):
  - Functions: provides reliable power, improves efficiency and prolongs battery lifespan
  - Sensing and decoding

Battery Modeling & SoC Estimation

- Two types of modeling:
  - Equivalent electrical-circuit.
  - Electrochemical.
- Two types of SoC estimation:
  - Direct (Coulomb Counting).
  - Indirect (EIS, Bayesian Estimator).
- Our proposed method: Electrochemical + Bayesian Estimator

Electrochemical Modeling



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ECM: State Equation

- Ficks Diffusion Equation:

$$\dot{c}_s = \frac{\partial c_s}{\partial t} = D_s \left[\frac{\partial^2 c_s}{\partial r^2} + \frac{2}{r} \frac{\partial c_s}{\partial r} \right], \quad (1)$$

with a couple of boundary conditions

$$\frac{\partial c_s}{\partial r} |_{r=0} = 0, \quad (2)$$

$$-D_s \frac{\partial c_s}{\partial r} |_{r=R_s} = \frac{J^{Li}}{F a_s}. \quad (3)$$

- Using the finite difference approximation, convert (1)- (3) into a set of PDE in time only:

$$\dot{\boldsymbol{c}}_s = \boldsymbol{A} \boldsymbol{c}_s + \boldsymbol{B} J^{Li}. \quad (4)$$

ECM: Measurement Equation

- Battery Terminal Voltage

  $V_T = \phi_{s,p} - \phi_{s,n} - R_f I$ (5)

- Solid Phase Potential (positive side)

  $\phi_{s,p} = \eta_p + \phi_{e,p} + U_p\left(\varphi_{se,p}\right)$ (6)

- Measurement Equation boils down to

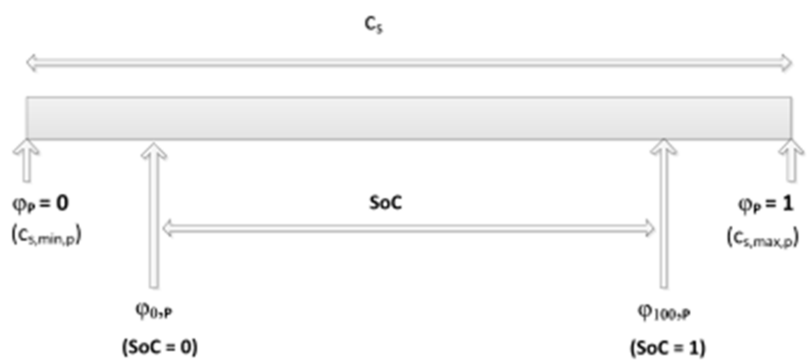
  $V_T = h(\boldsymbol{c}_s, I)$ (7)

- For various computational reasons, (4) and (7) are rewritten in terms of normalized solid-phase concentrations.

  $\varphi_s = \frac{\boldsymbol{c}_s}{c_{s,max}}$ (8)

What is State-of-Charge (SoC) ?

- SoC Definition w.r.t. positive side concentrations



- $$SoC = \begin{cases} 0 & \varphi_{se,p} < \varphi_{0,p} \\ \frac{\varphi_{se,p} - \varphi_{0,p}}{\varphi_{100,p} - \varphi_{0,p}} & \varphi_{0,p} \le \varphi_{se,p} \le \varphi_{100,p} \\ 1 & \varphi_{se,p} > \varphi_{100,p} \end{cases}$$

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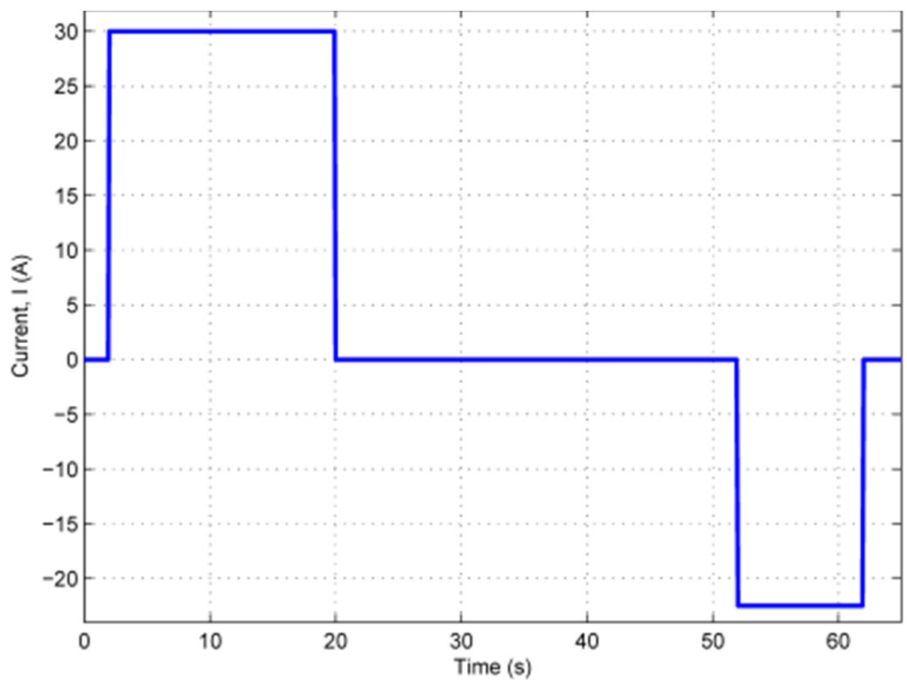
Potter SoC Tracking

- State equation (4) ➔ Time-invariant continuous-time linear model.
- Measurement equation (7) ➔ Single-dimensional nonlinear model.
- Convert the continuous-time state space model into a discrete-time model.
- A logical choice for SoC estimation is a square-root version of the Potter's estimator, which we call *Potter SoC Tracker* (PST).

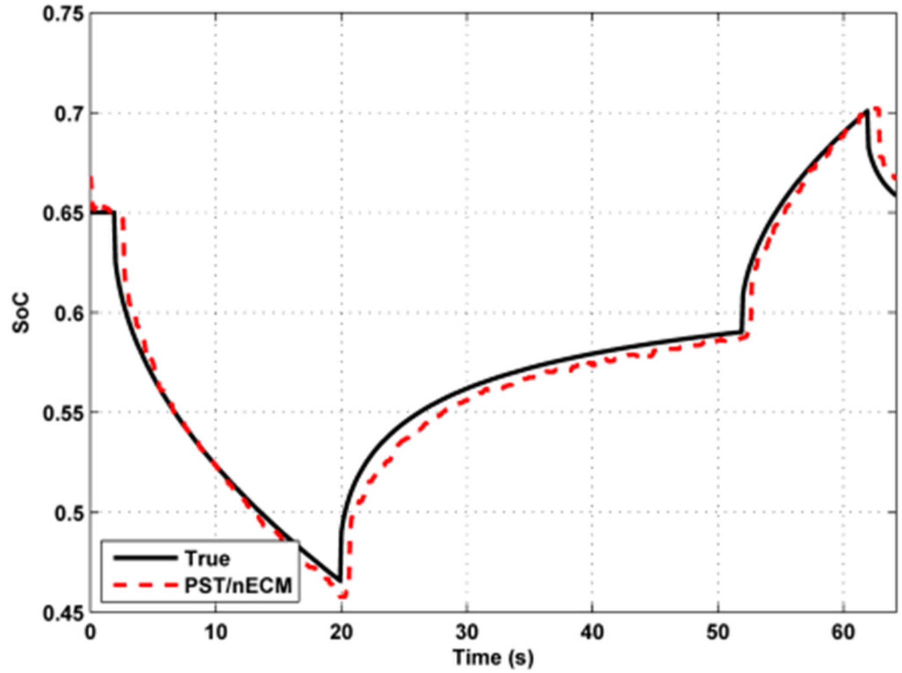
Computer Experiments: Setup

- Test Profiles:
  - Freedom CAR.
  - Pulse discharge.
- SoC estimators:
  - EKF/ECM.
  - PST/nECM (Proposed Method).
- Injected outlier measurements deliberately to check the robustness of the SoC estimators.

Results

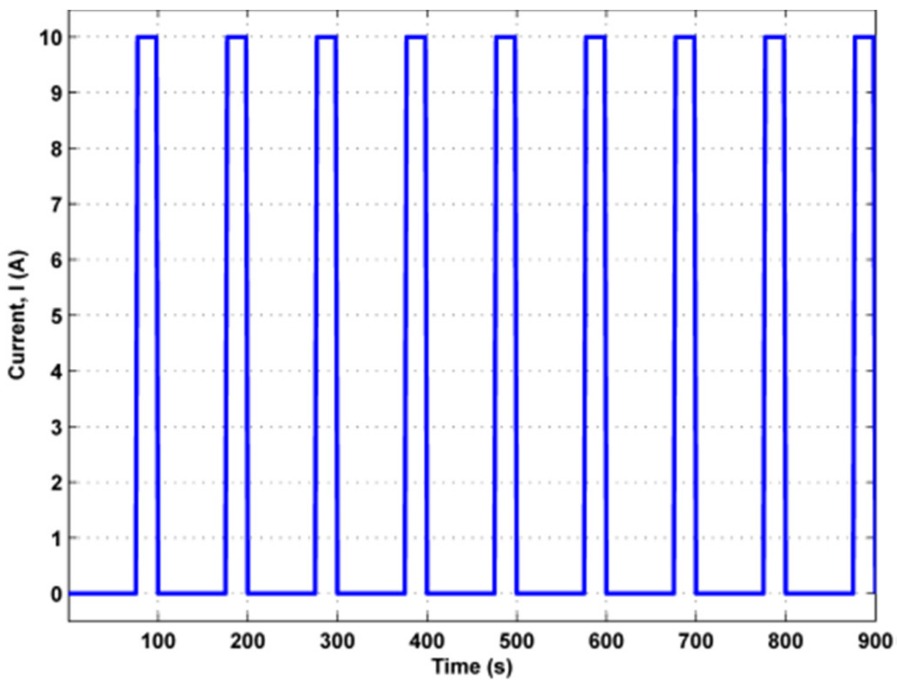


Current, I (A)
Time (s)
30
25
20
15
10
5
0
−5
−10
−15
−20
0
10
20
30
40
50
60

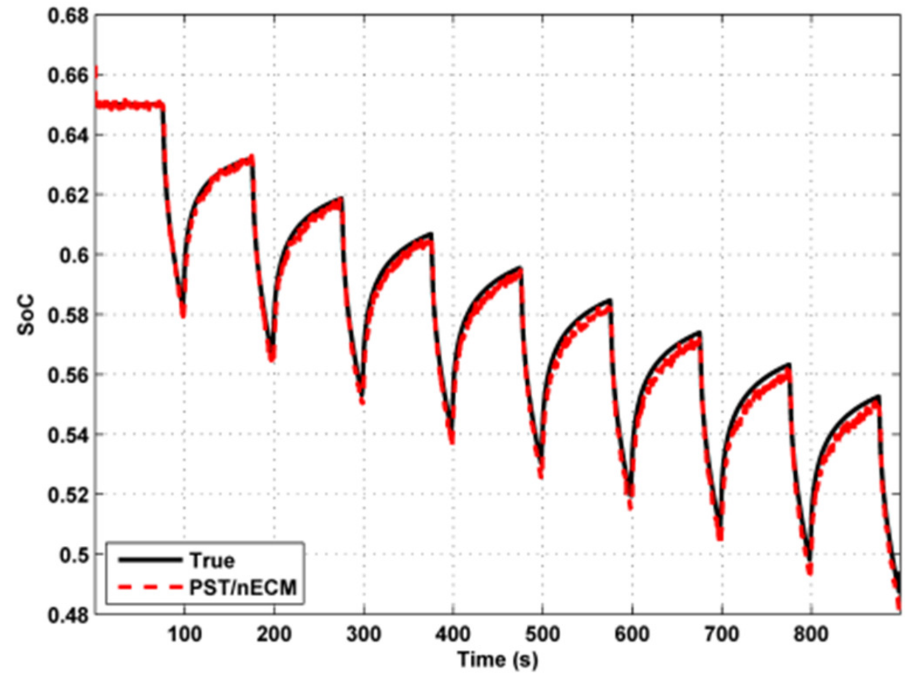


SoC
Time (s)
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0
10
20
30
40
50
60
True
PST/nECM

Results (Ctd)



Current, I (A)
10
9
8
7
6
5
4
3
2
1
0
100
200
300
400
500
600
700
800
900
Time (s)



SoC
0.68
0.66
0.64
0.62
0.6
0.58
0.56
0.54
0.52
0.5
0.48
True
PST/nECM
100
200
300
400
500
600
700
800
Time (s)

Summary

- Reduced Electrochemical Model into a State Space Model (SSM).
- Transformed the SSM into a normalized SSM.
- Selected the Potter estimator for SoC estimation.
- Demonstrated that the proposed method outperforms the traditional EKF based SoC estimation.
- Future Research:
  - Apply the proposed method to real cell data

Thank You