Adaptive Temperature Monitoring for Battery Thermal Management

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Agenda

- Battery Thermal Management: Review
- Lumped Thermal Model and Governing Equations
- Q-Adaptive Potter Filter for Skin/Core Cell Temperature Estimation
- Computer Experiments
- Summary and Future Research

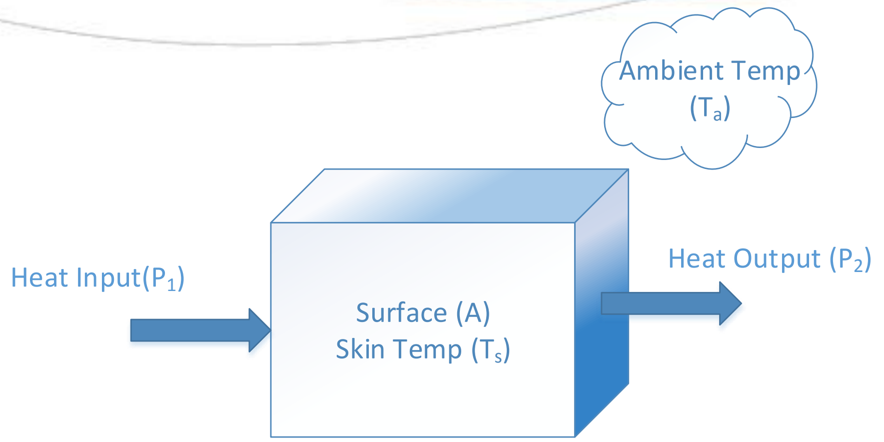
Battery Thermal Management System

- Temperature dependent cell parameters:
  - Available battery power
  - Available battery energy
  - Battery life
  - Safety
- Battery thermal management system (BTMS) ensures battery temperature and its spatial deviation to lie within an acceptable narrow range
- Existing BTMS techniques
  - Cabin air cooling/heating
  - Optimized coolant baffle design
  - Highly conductive coolant
  - Active (or Parallel) cooling/heating

Skin and Core Temperature Estimation

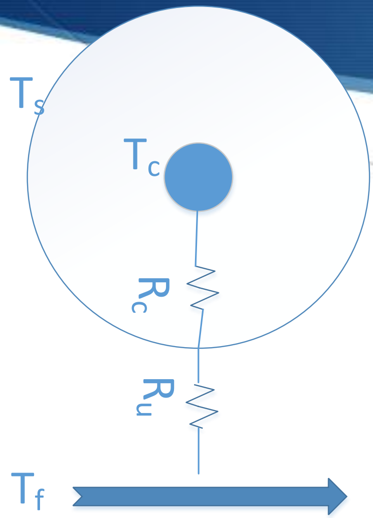
- Two types of modeling:
  - FEM (Finite Element Method): high fidelity, high computation
  - Lumped thermal model: less fidelity, less computation
- Objective: To estimate the core temperature from a lumped thermal model from skin temperature measurements
- Proposed method:
  - State-space modeling
  - Bayesian estimator (Adaptive Potter filter)

Lumped Thermal Model: Background



- Power balance equation:
  $$C\frac{dT}{dt} = P_1 - P_2 \qquad (1)$$
- Using Fourier's law of thermal conductance, we write
  $$P_2 = U\,(T_s - T_a) \qquad (2)$$

State-Space Modeling



- $C_c \dot{T}_c = \dot{s}_r + \frac{(T_s - T_c)}{R_c}$ (3)

  $C_s T_s = \frac{(T_f - T_s)}{R_u} - \frac{(T_s - T_c)}{R_c}$ (4)

  $\dot{s}_r = (OCV - V_t)I$ (5)

- Combining (3), (4) and (5) yields the state equation:

  $\dot{x} = \boldsymbol{Ax} + \boldsymbol{Bu}$ (6)

  where $\mathbf{x} = [T_c \quad T_s]^T$

- Measurement Equation:

  $T_s = [0 \;\; 1]\boldsymbol{x}$ (7)

Potter Filtering

- State equation (6) ➔ Time-invariant continuous-time linear model
- Measurement equation (7) ➔ Single-dimensional linear model
- Convert the linear continuous-time state space model into a discrete-time linear model.
- A logical choice for core and skin temperature estimation is using a square-root version of Potter's filter.

Q-Adaptive Potter Filtering

- To take into account model mismatches due to battery aging we rewrite the discrete-time state equation by adding Gaussian noise:

  $$\boldsymbol{x}_{k+1} = \boldsymbol{A}_d \boldsymbol{x}_k + \boldsymbol{B}_d \boldsymbol{u}_k + \boldsymbol{q}_k \qquad (8)$$

  where the process noise

  $$\boldsymbol{q}_k \sim N(0, \boldsymbol{Q}_k) \qquad (9)$$

- Compute $\boldsymbol{Q}_k$ using Maybeck's adaptive strategy:

  $$\boldsymbol{Q}_k = \frac{1}{N} \sum_i \Delta\boldsymbol{x}_i \Delta\boldsymbol{x}_i{}^T \qquad (10)$$

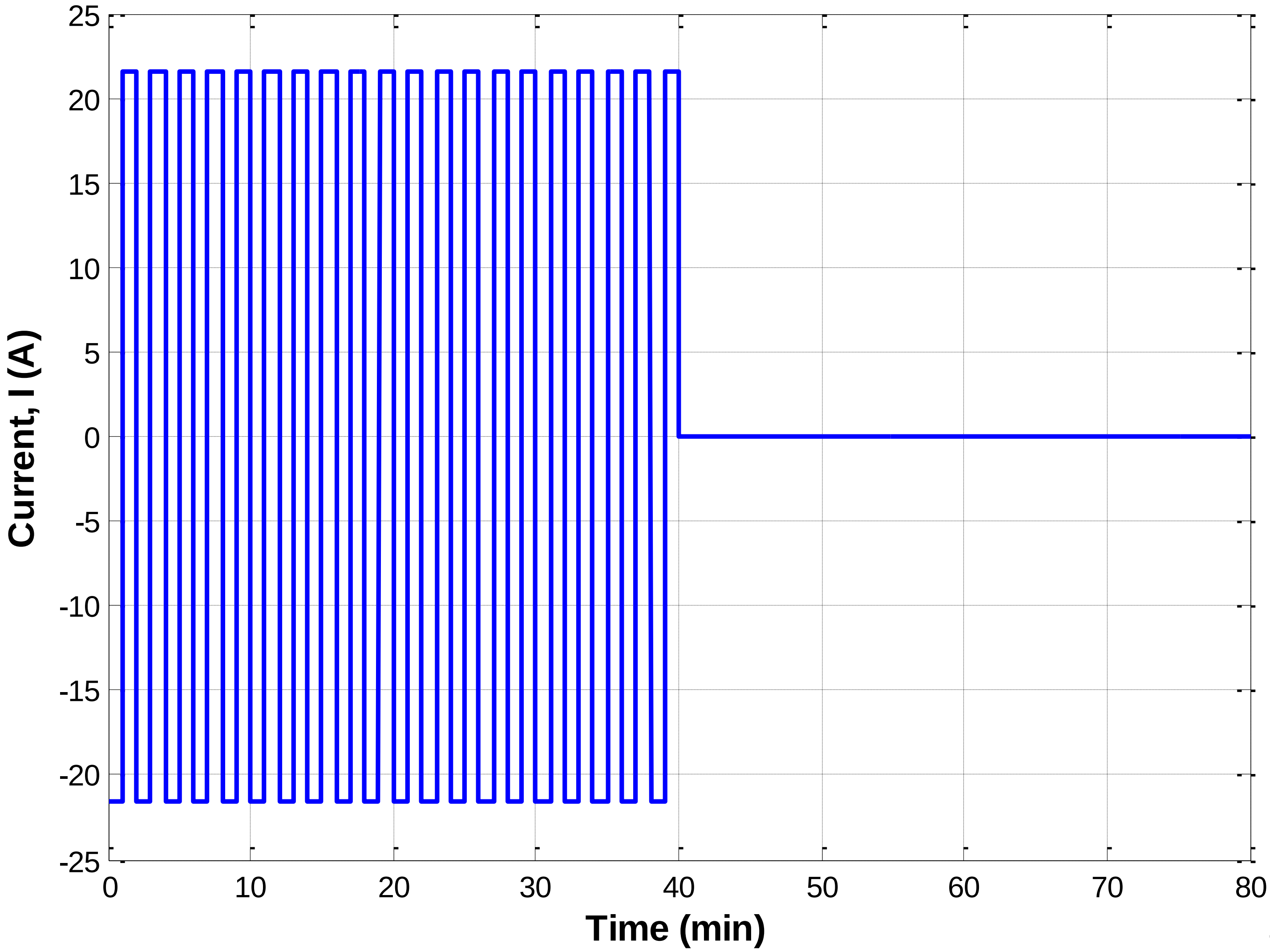
  where the state residual

  $$\Delta\boldsymbol{x}_i = \boldsymbol{x}_{k|k} - \mathbf{x}_{k|k\text{-}1} \qquad (11)$$

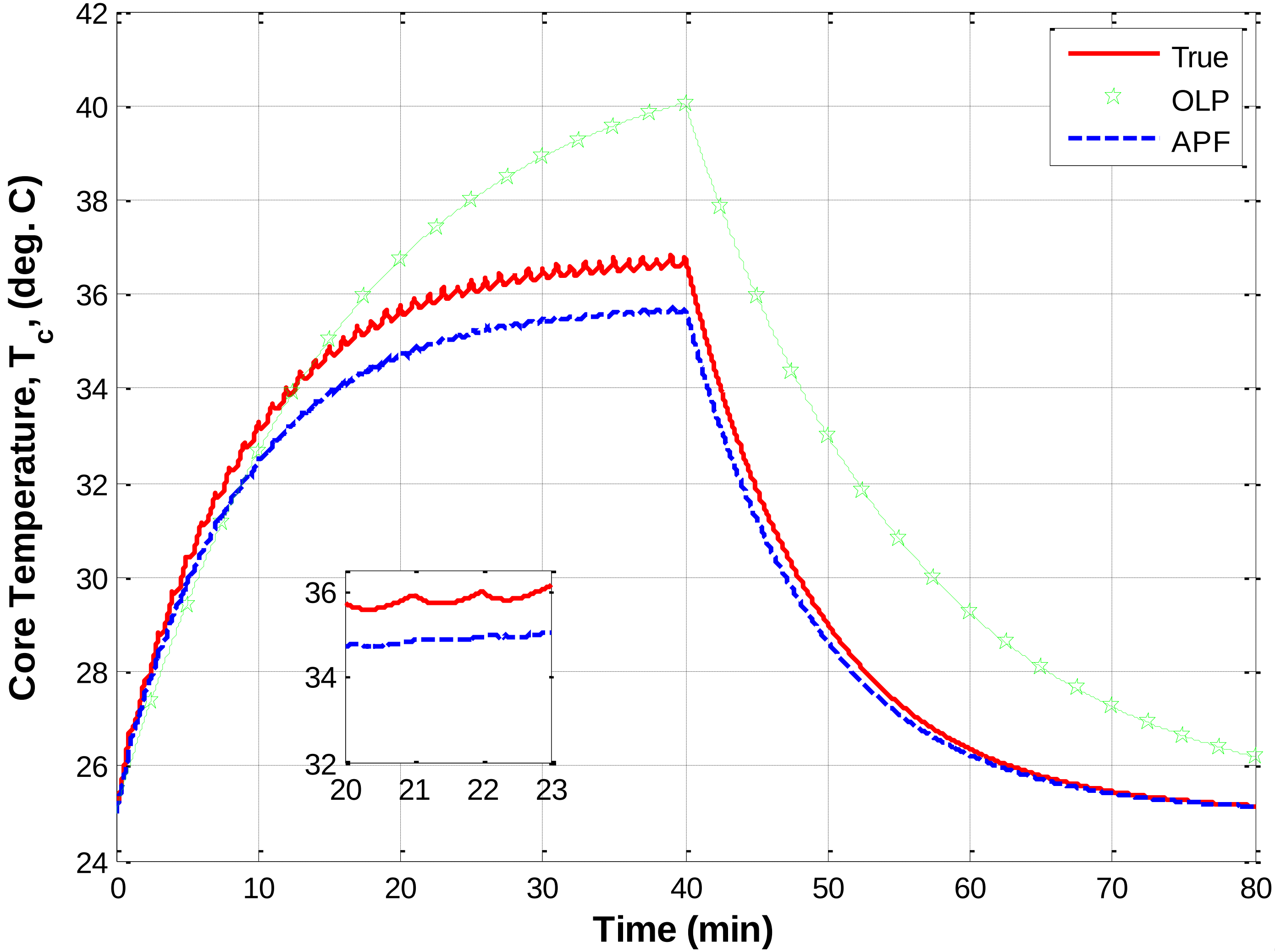
Computer Experiments: Setup

- Test Profile: Pulse charge/discharge current
- Temperature estimators:
  - Open Loop Prediction (OLP)
  - Q-Adaptive Potter Filter (APF) - Proposed Method
- During estimation, we deliberately introduced slight variations (from true) to cell parameters such as heat resistances and capacities.

Pulse Current Profile

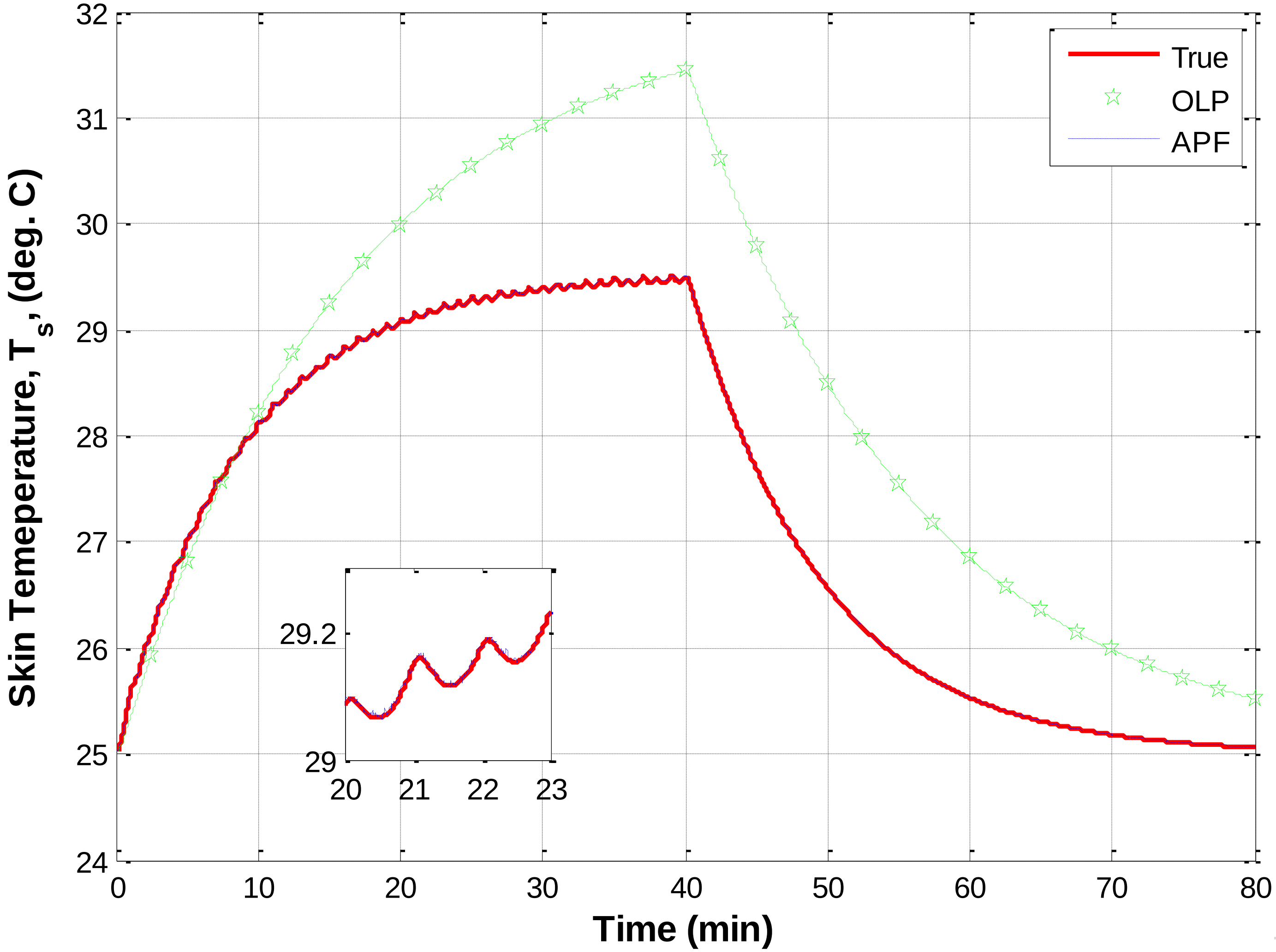


Results (Ctd)



True
OLP
APF
Core Temperature, T_c, (deg. C)
Time (min)
42
40
38
36
34
32
30
28
26
24
0
10
20
30
40
50
60
70
80
36
34
32
20
21
22
23

Results (Ctd)



Skin Temeperature, T_s', (deg. C)
Time (min)
True
OLP
APF
32
31
30
29
28
27
26
25
24
0
10
20
30
40
50
60
70
80
29.2
29
20
21
22
23

Summary

- Formulated a continuous-time linear state space model (SSM) from a lumped thermal model.
- Discretized the continuous-time SSM in the time domain.
- Applied the Q-adaptive Potter filter for skin and core temperature estimation.
- Demonstrated that the proposed method outperforms open-loop prediction.
- Future Research:
  - Extend the proposed method to battery packs

Thank You