Robustness and speed

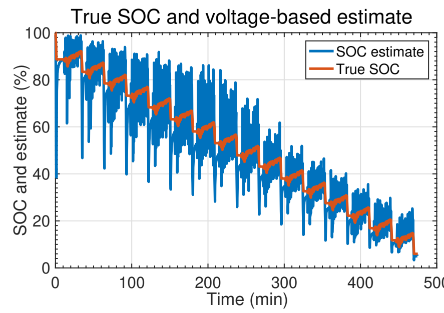
- Two issues remaining to consider
  - Speed: dual and joint filtering computationally complex
  - Convergence: do they converge to the correct solution?
- Consider convergence first
  - Dual and joint filtering adapt $\hat{x}$ and $\hat{\theta}$ so that model input–output relationship matches system's input–output data closely
  - No built-in guarantee that model state converges to any physical meaning
  - Usually, when employing KF, we desire that state converge to specific meaning
  - Special steps must be taken to ensure that this occurs; otherwise, state and parameter values will quickly diverge away from anything meaningful

Ensuring correct convergence

- A very crude cell model may be used, combined with dual/joint EKF/SPKF to ensure convergence of SOC state
- Specifically, the cell terminal voltage

$$\begin{aligned} v_k &\approx \mathrm{OCV}(z_k) - R_0 i_k \\ \mathrm{OCV}(z_k) &\approx v_k + R_0 i_k \\ \hat{z}_k &= \mathrm{OCV}^{-1}(v_k + R_0 i_k) \end{aligned}$$

- By measuring cell voltage under load, v_k, cell current i_k, and knowing R_0 and inverse OCV function, can compute noisy SOC estimate, $\hat{z}_k$



Ensuring SOC convergence

- Cell model used in KF has its output equation augmented with SOC: For example,

$$g(x_k, u_k, \theta) = \begin{bmatrix} \mathrm{OCV}(z_k) + M h_k - \sum_i R_i i_{R_i,k} - R_0 i_k \\ z_k \end{bmatrix}$$

- Dual/joint xKF run using modified model, with "measured" data used in update being

$$y_k = \begin{bmatrix} v_k \\ \hat{z}_k \end{bmatrix}$$

- "Noise" of $\hat{z}_k$ (short-term bias due to ignoring hysteresis and diffusion voltages) prohibit it from being used as primary SOC estimator, its long-term behavior in dynamic environment is accurate, maintains accuracy of SOC state in dual/joint xKF

Estimating SOH without full dual EKF/SPKF

- Full dual/joint EKF/SPKF is computationally expensive
- If precise values for full set of cell-model parameters are not necessary, then other methods might be used
- Can determine cell capacity and resistance using simpler KF-based methods
  - Same approaches as you might have seen in honors section of course 3, on bar-delta filtering
  - Since these are MMSE methods, estimate of total capacity using this approach is believed to be biased, and TLS methods are preferred

Estimating resistance using a simple xKF

- To estimate cell resistance using KF, formulate simple model

$$\begin{aligned} R_{0,k+1} &= R_{0,k} + r_k \\ v_k &= \mathrm{OCV}(z_k) - R_{0,k} i_k + e_k, \end{aligned}$$

  where cell resistance $R_{0,k}$ modeled as a constant value with a fictitious noise process r_k allowing adaptation
- v_k is crude estimate of cell's voltage, i_k is cell current, e_k models estimation error
- If estimate of z_k is available from an external source, we simply apply KF to this model to estimate cell resistance
- Above model may be extended to handle different values of resistance on dis/charge, or at different SOCs, or at different temperatures, for example

Estimating capacity using a simple xKF

- To estimate cell capacity using KF, formulate simple cell model

$$\begin{aligned} Q_{k+1} &= Q_k + r_k \\ d_k &= z_k - z_{k-1} + \eta_{k-1} i_{k-1} \Delta t / Q_{k-1} + e_k \end{aligned}$$

- Second equation is a reformulation of the SOC state equation such that the expected value of d_k is equal to zero by construction
- Again, a KF is constructed using the model defined by these two equations to produce a capacity estimate
- As KF runs, computation for d_k in second equation is compared to known value (zero, by construction), and difference is used to update capacity estimate
- Note that good estimates of the present and previous states-of-charge are required, possibly from a KF estimating SOC

Summary

- It is very difficult to tune dual/joint xKFs due to the very different timescales of states and parameters
- By default, dual/joint xKFs will tend to diverge away from meaningful state and parameter values so must take special steps to make estimates robust
- Augmenting output with approximate SOC estimate helps with this
- Also, if it is not necessary to estimate entire model parameter vector, can estimate only those desired, as illustrated with examples for resistance and total capacity