Impact of SOC-estimate noise

- The simulation results have illustrated a few key properties of the four methods we used to estimate total capacity:
  - Noise on the SOC estimates must be considered in order to estimate battery total capacity properly
    - Least squares, weighted least squares, and other similar methods simply fail
    - They give biased estimates of total capacity, with unreliable error bounds
    - Methods related to total least squares, where noises on the SOC estimates are explicitly recognized and incorporated in the calculations, are required for reliable total capacity estimation

WTLS is superior method

- The simulation results have illustrated a few key properties of the four methods we used to estimate total capacity:
  - WTLS, in principle always gives the best results
    - However, we have seen that TLS and AWTLS methods can give better results in practice because they can be initialized with nominal capacity estimate
    - Furthermore, since TLS and AWTLS give nice recursive solutions, one of them should always be used instead of WTLS

Impact of update interval

- The simulation results have illustrated a few key properties of the four methods we used to estimate total capacity:
  - If the measurement update interval m_i is constant, and therefore $\sigma_{x_i} = k\sigma_{y_i}$ for all measurements, TLS and AWTLS give identical results
    - Therefore, the simpler TLS method is preferred
    - However, if $\sigma_{x_i} \neq k\sigma_{y_i}$, the AWTLS method gives better results than TLS, and sometimes TLS fails
    - Yields greatly improved total-capacity estimates for BEV application where updates are done when charging battery, because of the reduction in σ_{x_i} due to knowing one SOC value exactly
    - AWTLS always gives results at least as good as the other methods

Noises on accumulated Ah

- The simulation results have illustrated a few key properties of the four methods we used to estimate total capacity:
  - We assumed that noises that contribute to σ_{y_i} are due to current-sensor errors
    - These can include gain, bias, noise, and nonlinear errors: have considered only noise errors here
    - Gain and nonlinear errors will bias all methods; however, believe that the biased value of the total capacity estimate will be consistent with the perceived capacity of the battery pack if same current sensor is used to compute battery pack total capacity estimate and to monitor pack operations
    - Bias error can be subtracted in a BEV setting if we can assume that the Coulombic efficiency of the cells is $\eta \approx 1$ by matching the discharged ampere hours from usage with the charged ampere hours

Uncertainty in final result

- The simulation results have illustrated a few key properties of the four methods we used to estimate total capacity:
  - Output error bounds on total capacity estimate, even with optimum WTLS estimator, are larger than some might expect
    - Underscores need for a method that predicts not only estimate, but also dynamic error bounds on estimate, as do the ones proposed here
    - Without dynamic error bounds, user of total-capacity estimate has no idea how good or bad that estimate is
    - If estimate is used to compute battery pack available energy, for example, energy estimate may be overly optimistic or overly pessimistic, neither of which is acceptable

Summary of this course

- We have now looked at the fundamental state and parameter estimation problems that must be solved by a BMS
- In this course, you learned
  - Physical mechanisms of battery degradation
  - That estimating cell resistance is reasonably straightforward (and a simple method to do so) since it is a very “observable” quantity
  - That estimating cell total capacity is quite difficult to do well, since it is not a very observable quantity
- In particular, you learned that commonly used LS/WLS methods should *not* be used, and that some kind of TLS-based method should be used instead
- AWTLS yields good compromise between efficient computation, quality of results

Decision point

- This brings us to the end of the non-honors version of course 4 in the BMS algorithms specialization
- Decision point:
  - Honors track has one more week in course 4, looking into application of xKF to parameter estimation
  - Can estimate resistance, capacity, but also other model parameter values (at least in principle)

Where from here?

- Course 5 focusses on topics in battery control
- First, you will learn about balancing/equalizing a battery pack
  - This includes reasons why balancing is needed, some top-level circuits that can perform balancing, and some balancing strategies
- Then, you will learn about computing power limits
  - You learned some simple methods to do so in the first course
  - You will learn some more advanced methods in the next course, which take into account entire dynamic state estimate from xKF

Credits

Credits for photos in this lesson

- Fork in road on slide 2: By Mark Turnauckas, [CC BY 2.0 (`https://creativecommons.org/licenses/by/2.0/`)], `https://www.flickr.com/photos/marktee/5923492105`