# Feasible Projects for May 01, 2022 Deadline

Title: **Performance Bounds of Electrochemical Impedance Spectroscopy for Battery Parameter Estimation**

Synopsis: The CRLB of parameter estimation will be derived in time domain for model 4. Then FFT will be used to convert to frequency domain and estimate parameters using the LS approach. The noise will be added to time domain measurements, according to the SNR that we define. Since this is model-4 there is now Warburg impedance, but the parameter estimation approach will be the same. The NMSE vs SNR curve will show how much performance loss is created by noise and the conversion to frequency domain.

Team: Rohit, Niladri

Title: **Computing Tabular OCV models from experimental OCV-SOC Characterization Data**

Synopsis: earlier, we constructed tabular OCV-SOC model from functions. This time, we will show how to do it from the data itself. Instead of analog integration/differentiation we will use numerical integration/differentiation.

Team: Sneha, Bharath

Title: **Li-ion Battery Resistance Model Using Optimal Parameter Estimation**

Synopsis: The details are already discussed. Why the parameter estimation is “optimal”? we will prove that theoretically.

Team: James, Panch

Title: **Fast OCV-SOC Characterization of Li-ion Batteries**

Synopsis: So far, the OCV characterization data collection takes 60+ hours. How to reduce that? We will try the following data collection approach and prove that the resulting OCV is very similar to the one obtained from traditional OCV data (collected using a c/30 current).

1. Start with a full battery
2. Discharge by C/2 for 1 hour (remaining capacity is C/2)
3. Discharge by C/4 for 1 hour (remaining capacity is C/4)
4. Discharge by C/8 for 1 hour (remaining capacity is C/8)
5. Discharge by C/16 for 1 hour (remaining capacity is C/16)
6. Discharge by C/32 for 1 hour (remaining capacity is C/32)
7. Do 2-6, this time in the charging direction
8. The resistance estimation pulse is applied for all the profiles in 2-7 at 10 min interval (it takes seconds and does not alter SOC)

The total characterization time is 10 hours (compared to 60 before). Once we are done with this, we will have a good sense of whether we can reduce the characterization time even more. Shorter characterization time is a boon to BMS development. In the future, we will look into doing the same for SOH characterization as well (i.e., find ways to reduce characterization time).

Team: Panch, James

Title: **Comparison of New and Used Battery Equivalent Circuit Model Parameters Using Electrochemical Impedance Spectroscopy at Multiple SOC Levels**

Synopsis: We need to repeat the previous experiments (i.e., doing EIS and time-domain pulse at different SOC levels) with used vs. new batteries. I have 4 brand new and 4 used Ni MH batteries of the same type. Let’s see how they compare.

Team: Rohit

Title: **Electrochemical Impedance Spectroscopy Using Chirp Signals**

Synopsis: Traditional EIS takes time. A chirp signal might be able to reduce that. It is already known. What we will do is that we will generate different chirp signals and find out what parameters are good for battery parameter estimation. This will be done using our Matlab-based battery simulator (that can simulate a battery with model-4 ECM (no Warburg impedance and inductance).

Team: Rohit

Title: **Experimental Validation/Modelling of Hysteresis in Li-ion Batteries**

Synopsis: A special loading profile (see picture below) will be created to measure the OCV (using our recent model) at different SOC values. The same SOC will be reached through several paths. For example, in the figure, 90% SOC is reached 8 times (considering travel forward and backward). Our first question: is the OCV at a certain SOC “path dependent”? if so, we will try to fit the hysteresis model that we have in the BMS course to see how accurately we can model the hysteresis.

A picture containing diagram

Description automatically generated

Team: Prarthana, Shena

Title: **Linear Estimation With Noisy Models: Exact Performance Analysis and Applications in Battery Parameter Estimation**

Synopsis: Earlier, we derived a theoretical CRLB for estimation with noisy models. It is already found that our derivation is approximate, and it only works in high SNR. This time, we will try to come up with the correct derivation. We already have an approach suggested by Prof. Pattipati. A paper being read by Pradeep might be useful as well.

Team: Pradeep, Sneha

Title: **Battery Thermal Model Identification And Surface Temperature Prediction: Hardware in the Loop Demonstration**

Synopsis: HIL demonstration of Pradeep’s surface temperature prediction work.

Team: Pradeep

Title: **Robust Extended Kalman Filtering for State of Charge Estimation in Batteries: Demonstration Using Real Data**

Synopsis: Earlier, we developed a robust EKF and demonstrated it for model-2 using simulated data. The reason we didn’t demonstrate in real data was that the battery behaviors significantly changes at low SOC, indicating the need for model-3. We will derive and demo model-3 this time. That should be sufficient to demonstrate using real data. If needed, model-4 will also be derived and data from low temperatures will be tested.

Team: Prarthana

Title: **Robust Approach to Battery Equivalent Circuit Model Parameter Estimation: Observability analysis and Demonstration Using Real World Data**

Synopsis: Earlier, we derived an approach to estimate ECM parameters independently without requiring any SOC information. The proposed approach works optimally for models ECM1 and ECM-2. For ECM-3 and ECM-4, we will explore the following:

* Observability analysis
* Differential voltage approach (instead of using SOC, we will use previous information to subtract OCV value; experiments show that this method gives better estimates. Why? The answer might lie in the observability analysis or the CRLB based analysis
* If the differential voltage approach gives satisfactory performance, we will stop. Otherwise, we will implement TLS based estimator – that should help. If the differential OCV worked, TLS will be kept for a future paper.

Team: Prarthana, Sneha

Title: **Robust Approach to Battery Capacity Estimation: Demonstration Using Real Data**

Synopsis: Previously in [1], we derived a capacity estimation approach using LS and RLS approaches. There is a need to verify using real data. We will collect data from our Arbin for this study.

Team: Sneha

[1] Balasingam, B., G. V. Avvari, B. Pattipati, K. R. Pattipati, and Y. Bar-Shalom. "A robust approach to battery fuel gauging, part II: Real time capacity estimation." Journal of Power Sources 269 (2014): 949-961.

Title: **An optimal grid filter for battery SOC estimation**

Synopsis: Unlike regular application of state-space models and filtering, the desired state space (of SOC) is limited, i.e., SOC \in [0,1]. The state space can be divided into a grid of required resolution. The grid filter can be optimal even if the model is non-liner. This could be an interesting (and very novel) approach to SOC estimation.

Team: Sooraj, Prarthana

Title: **Extended Kalman Filter for State of Charge Estimation Using Tabular OCV Model**

Synopsis: The tabular OCV model is useful for computationally restrictive environments. How do we verify the performance of the proposed tabular OCV-SOC model approach in those respective environments? Matlab allows to simulate these environments (fixed-point simulation). The goal is to compare the performance of a particular fixed-point system (8-bit, 16-bit etc.) against high resolution implementations, e.g., standard computer.

Team: Rohit, Pradeep, Sneha

Title: **Demonstration of Benchmarking for Battery Fuel Gauges**

Synopsis: Evaluate the accuracy of commercially available BFGs using the three metrics introduced in [1]

Team: James, Panch, Pradeep, Rohit, Cole

[1] Avvari, G. V., Pattipati, B., Balasingam, B., Pattipati, K. R., & Bar-Shalom, Y. (2015). Experimental set-up and procedures to test and validate battery fuel gauge algorithms. *Applied energy*, *160*, 404-418.

# Other Possible (??) Titles

Title: **Optimal Current Profile Selection for Battery Internal Resistance and OCV Estimation**

Synopsis: This is the optimization that arose last semester. Whoever solves it can take the lead authorship and write it I guess. There are multiple approaches – depends on how lengthy and difficulty each approach is.

?? I don’t think progress is likely in the next few months

Team: ??