A novel approach to state/parameter estimation and optimal fast-charging

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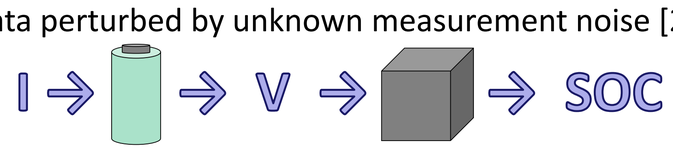
Background

A battery management system (BMS) typically employs an equivalent circuit model (ECM) to perform estimation of the model states and parameters. Simple models are chosen for their low computational cost and identifiability.

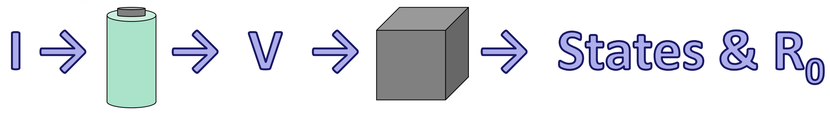
New methods are required to unlock the power of physics-based models to improve battery performance and longevity.

We benchmark a new approach, that is capable of extending to nonlinear models, using an ECM and synthetic data.

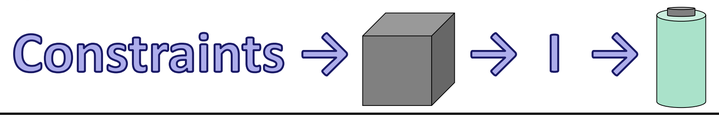
1) **State-of-charge (SOC) estimation** from current-voltage data perturbed by unknown measurement noise [2].



2) **Joint state-parameter estimation** (of all model states along with an unknown parameter) from noisy data.



3) **Constrained, optimal fast-charging prediction** to identify the optimal input current to achieve the shortest possible charging time subject to a given set of constraints [4].



Method

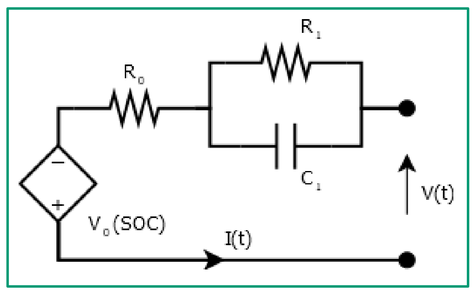
We test the capabilities of a new approach to nonlinear optimisation, based on recent developments in the field of measure-moment theory [1].

The measure-moment approach is unique in its ability to obtain globally optimal estimates of trajectories. Unlike existing methods, trajectories are not computed via discretisation in time but are instead estimated via **polynomial minimisation**. This means that initial conditions are not required and the evolution of variable parameters (with unknown dynamics) may be estimated. The steps are:

1. Write down an analogous optimisation problem in terms of measures on feasible sets
2. Convert from measures to moments to form a linear matrix inequality (LMI) problem
3. Truncate the LMI problem to a finite number of moments, or "relaxation order"] repeat for higher orders until the cost converges
4. Solve this problem numerically to obtain estimates of the optimal moments
5. Convert back from moments to find the support of the measures

The LMI problems can be constructed and solved numerically [3] using a set of open-source packages for Matlab - namely, Gloptipoly3, Yalmip, Mosek or SeDuMi, and momgraph.

The restriction is that the cost criterion and constraints must be polynomial in nature. For example, differential equations with polynomial dynamics, such as the Thévenin model for a battery:



$$\frac{dSOC}{dt} = \frac{I(t)}{Q},$$

$$\frac{dV_{RC}}{dt} = -\frac{V_{RC}}{R_1 C_1} + \frac{I(t)}{C_1},$$

$$V(t) = V_0(SOC) + V_{RC} + R_0 I(t).$$

Parameter	Value
Capacity, Q	15 Ah
Resistance, R_1	2 mΩ
Capacitance, C_1	8 MF
Series resistance, R_0	5 mΩ

Open-circuit voltage:
$V_0(x) = 3.64 + 0.55x - 0.72x^2 + 0.75x^3$

A variable R_0 is identifiable from current-voltage data when the input current is non-zero [5].

Are you interested in fitting battery models to data?

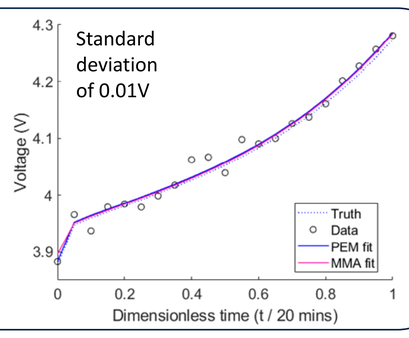
Results

1. SOC estimation

Problem: Estimate SOC(t=0) and the capacity Q, given the other parameters, input I=30 A and output V(t)+noise for 0<t<20 min. Compare the **measure-moment approach** (MMA) versus **prediction error minimisation** (PEM).

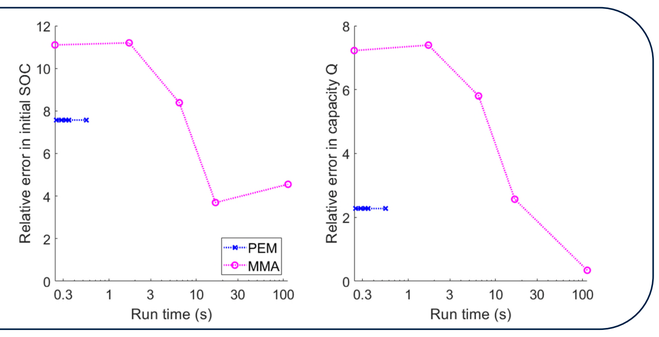
Fit to data

Voltage data measured every 30 s.



Error vs. run time

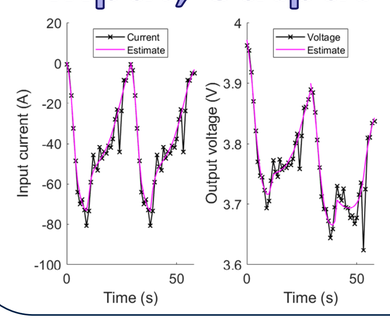
For different starting points (PEM) and different relaxation orders (MMA) of r = 3,4,5,6,7.



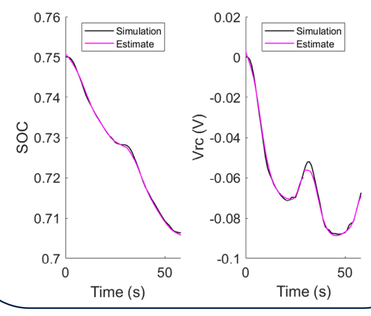
2. Joint state-R_0 estimation

Problem: Estimate SOC(t), V_{RC}(t) and series resistance R_0(t), given the other parameters, input current and output V(t)+noise for 0<t<1 min. The **measure-moment approach** is able to detect a fault (discontinuity) in R_0 at t = 43 s.

Input, output

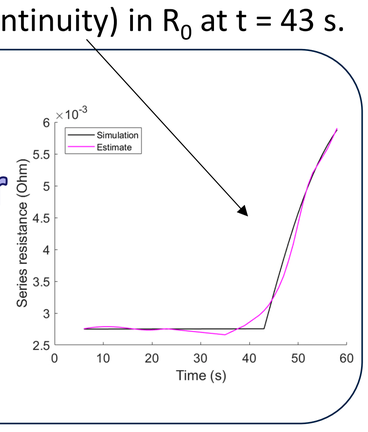


State estimates



Variable parameter estimate

Jointly estimated along with the states using a relaxation order of r=4.

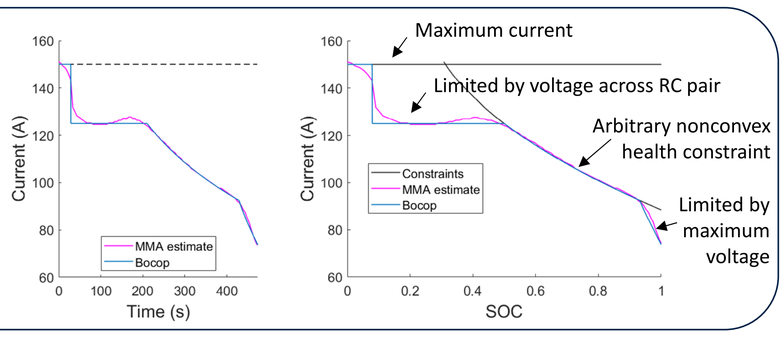


3. Optimal fast-charging prediction

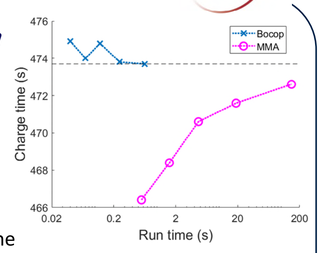
Problem: Estimate I(t), given the other parameters and a set of constraints, which gives the shortest charge time. Compare the **measure-moment approach** (MMA) versus **Bocop** [6] **nonlinear optimal control solver**.

Optimal current

Constraints are required to ensure safety and to prevent degradation [4].



Accuracy vs. run time



The optimal charge time for different numbers of time points (Bocop) and different relaxation orders (MMA) of r = 3,4,5,6,7.

Conclusions

We conclude that the measure-moment approach (MMA) is a versatile method for tackling optimisation problems relevant to the battery industry.

Due to its global (rather than discretised) nature, the MMA is stable even when tackling problems which are **nonlinear and nonconvex**, by considering an analogous (but linear and convex) problem in the space of measures on a compact set, which can be solved numerically. Although not the fastest method, this work opens the way towards estimating states, parameters and optimal input currents for nonlinear physics-based models.

References

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Acknowledgements

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