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Adaptive Particle MCMC for non-linear battery state-space models

State-space models have become core tools in industry as the basis of digital twin technology, enabling online system state monitoring. Advanced Bayesian methods, such as Particle Markov Chain Monte Carlo (PMCMC), may be used for state and parameter inference in non-linear state-space models. The approach combines particle filtering to approximate the hidden state posterior distribution and a Metropolis-Hastings sampler for model parameter proposal. An adaptive PMCMC framework is presented, consisting of multiple stages: first phase sees effective exploration of the parameter-space, achieved by inflating filter hyperparameters which govern particle diversity; during refinement phases posteriors approach stationary distributions as proposal acceptance rate and data subsampling step size are gradually decreased.

Presented methodology is applied to an equivalent circuit model of a lithium-ion battery for assessment of State of Charge and State of Health –battery characteristics useful for predictive maintenance and remaining useful life estimation. Versatility of adaptive PMCMC across different battery designs and charging conditions is confirmed via experiments using real battery cycling data. A comparative assessment against an electrochemical model, typical for lithium-ion battery simulation, reveals significant trade-offs. While the electrochemical model boasts higher interpretability through physical parameters, it suffers from numerical instability and disproportionate sensitivity to inputs. On the other hand, the proposed adaptive PMCMC framework features superior robustness and comprehensive uncertainty quantification at a cost of longer computation times. However, the inherent structure of presented methodology lends itself to parallelization for efficient computing and long-term system degradation monitoring through Bayesian updating.

Special/ Invited session

Classification

Both methodology and application

Keywords

state-space models; Bayesian inference; lithium-ion batteries

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