ECCE 2021 Tutorial Information

1. Tutorial Title

Applying Artificial Intelligence to Battery State Estimation

2. Instructor Team

McMaster University
Carlos Vidal (vidalc2@mcmaster.ca) and Phillip Kollmeyer (kollmeyp@mcmaster.ca)

MathWorks
Javier Gazzarri (jgazzarr@mathworks.com)

3. Abstract

This tutorial will teach the entire process necessary to create, test, and deploy machine learning algorithms which estimate battery state of charge or other states and properties of interest. Traditional state estimation methods depend on battery models that cannot always capture the complex nonlinear, temperature-dependent characteristics inherent in battery electrochemistry. Machine learning simplifies the process by treating the battery as a black box. The relation between states of interest and measured battery parameters are fit to a neural network, which is a series of matrix calculations containing hundreds or thousands of learnable parameters. Machine learning has potential to achieve better accuracy than conventional battery modeling and state estimation techniques and is a promising solution for a wide range of commercial and industrial applications.

Battery state estimation and machine learning theory will first be introduced, along with a discussion of different types of machine learning methods that can be applied to battery applications. Then the steps to create a machine learning algorithm – an experimental collection of data, defining network configuration and hyperparameters, training, and testing – will each be discussed in detail. A case study comparing a non-recurrent feedforward neural network with a recurrent, LSTM-based neural network will be provided, demonstrating that both network types can perform very well for realistic vehicle drive cycles over a wide range of temperatures. The tutorial will also include an interactive session where the attendees will train and test neural networks for the state-of-charge estimation via example data and code executing in MATLAB Online, which can run in any web browser.

Following the training and testing process, the next step is to deploy the networks in hardware and evaluate their real-time performance and computational load. The method of saving a neural network as a MATLAB object for direct use in Simulink, auto-generation of C-code, and deployment to a real-time target, such as a battery management system, will be demonstrated. Example results showing processor time as a function of algorithm type and several learnable parameters will be given. It will provide insights into machine learning algorithms' suitability for large battery packs with a hundred or more cells.

The tutorial will also provide several other examples of how to apply machine learning to battery applications, including (1) use of machine learning in place of equivalent circuit models, (2) estimation of temperature to reduce the need for physical sensors in a battery pack, and (3) state of health estimation.

6. Instructor Biographies

Javier Gazzarri has worked as an application engineer at MathWorks for 10 years, focusing on the use of simulation tools as an integral part of model-based design. Much of his work gravitates around battery modeling and simulation, from cell- to system-level, parameter estimation for model correlation, battery management system design, thermal management, degradation, and state estimation using observers. Before joining MathWorks, Javier worked on fuel cell modeling at the National Research Council of Canada in Vancouver, British Columbia. He has a bachelor's degree in Mechanical Engineering from the University of Buenos Aires (Argentina), a master's degree (inverse methods for sensor design), and a PhD degree (solid oxide fuel cell degradation and impedance spectroscopy) both from the University of British Columbia (Canada).

Phillip Kollmeyer is a Senior Principal Research Engineer at McMaster University in Hamilton, Ontario, Canada. Phillip is the lead engineer for the forty-five-member team working on the Car of the Future project, which is sponsored by Fiat Chrysler Automobiles and Canada's Natural Sciences and Engineering Research Council (NSERC). His research focuses on state estimation, thermal management, modeling, and aging of electrochemical energy storage systems, and the application of neural networks for modeling and state estimation. Phil has a Bachelor's degree, MASc degree (electric vehicle drivetrains), and PhD degree (hybrid energy storage and electric truck traction systems), all in electrical engineering and from the University of Wisconsin-Madison (USA).

Carlos Vidal received his B.S. in Electrical Engineering in 2005 from Federal University of Campina Grande (UFCG), MBA with a concentration in Project Management from Getulio Vargas Foundation (FGV) in 2007, his M. A Sc. in Civil and Environmental Engineering from Federal University of Pernambuco (UFPE) in 2015, Brazil. In 2020 he obtained his Ph.D. in Mechanical Engineering from McMaster University, Hamilton, ON, Canada. He is currently working as Postdoctoral Research Fellow at the McMaster Automotive Research Centre (MARC). Before joining McMaster, he has been gathering industry experience for over a decade from several engineering and management positions. His main current research areas include artificial intelligence, modelling, and energy storage applied to electrified vehicles and battery management systems.