A State of Charge Estimation System for a Semi-Autonomous Electric Wheelchair

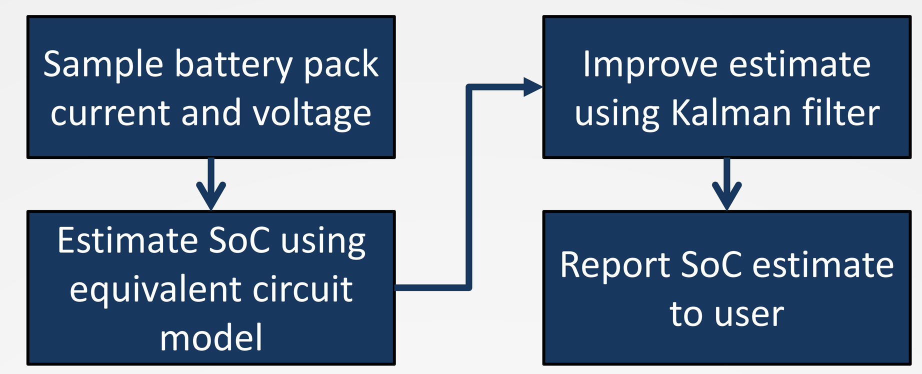
[1]Department of Electrical Engineering
The Pennsylvania State University

Christopher Miller[1,2], Kelilah Wolkowicz[2], Dr. Sean Brennan[2]

[2]Intelligent Vehicles and Systems Group
Department of Mechanical and Nuclear Engineering
The Pennsylvania State University

Motivation: Improve Energy Monitoring for Electric Wheelchairs

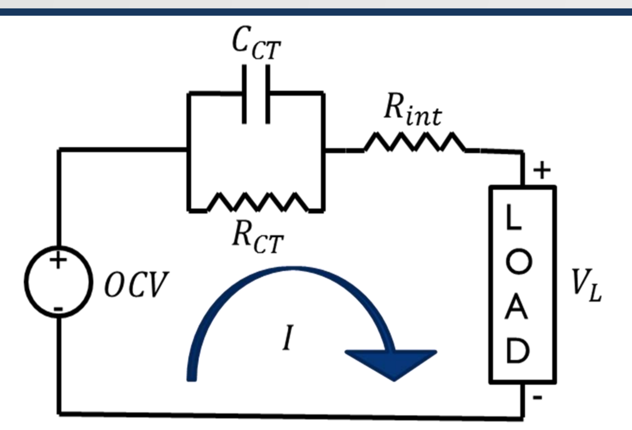
This project sought to develop a state-of-charge (SoC) estimator for the battery pack on an electric wheelchair. An existing intelligent wheelchair platform was retrofitted with a custom power monitoring system to rapidly monitor battery pack voltage and system current draw. A 2nd order, equivalent circuit model was developed and parameterized for the wheelchair's Pb-acid battery pack. To simplify SoC estimation, a vehicle fuel gage model was developed. Similar to a vehicle's fuel gage, the battery's SoC estimate is least accurate at it's extrema due to non-linarites at the maximum and minimum fuel estimates. A Coulomb accumulator was incorporated to estimate SoC in the non-linear regions of the battery pack's Open Circuit Voltage (OCV) - SoC curve. This region is defined as the area where the SoC is greater than 80% or less than 20%. In the linear region of the SoC curve, a linear Kalman filter was incorporated for SOC estimation. The estimator's functionality was verified in both simulation and experimentally.



High-level block diagram of the SoC Estimator

Nearly 150,000 individuals in the United States rely on electric wheelchairs to regain lost mobility. As a result, these individuals are dependent on a battery pack to drive their mobility. If their battery pack dies, a wheelchair bound individual may become stranded without a means of moving to their desired location, thus, limiting their freedom-of-mobility. Presently, electric wheelchairs have onboard battery monitors that lack the accuracy users desire to predict the remaining electric range. Discussions with an electric wheelchair user indicate that users fear total battery discharge as it may result in stranding. In more advanced wheelchairs, such as autonomous and semi-autonomous wheelchairs, a precise battery estimation method is essential as users of such "intelligent" wheelchairs may be unable to self-monitor a feedback display due to severe disability. This research aims to help wheelchair-bound persons and fill a gap in wheelchair and assistive technology literature.

Methods: Battery Modeling, Characterization, Algorithm Design, and Charge Estimation

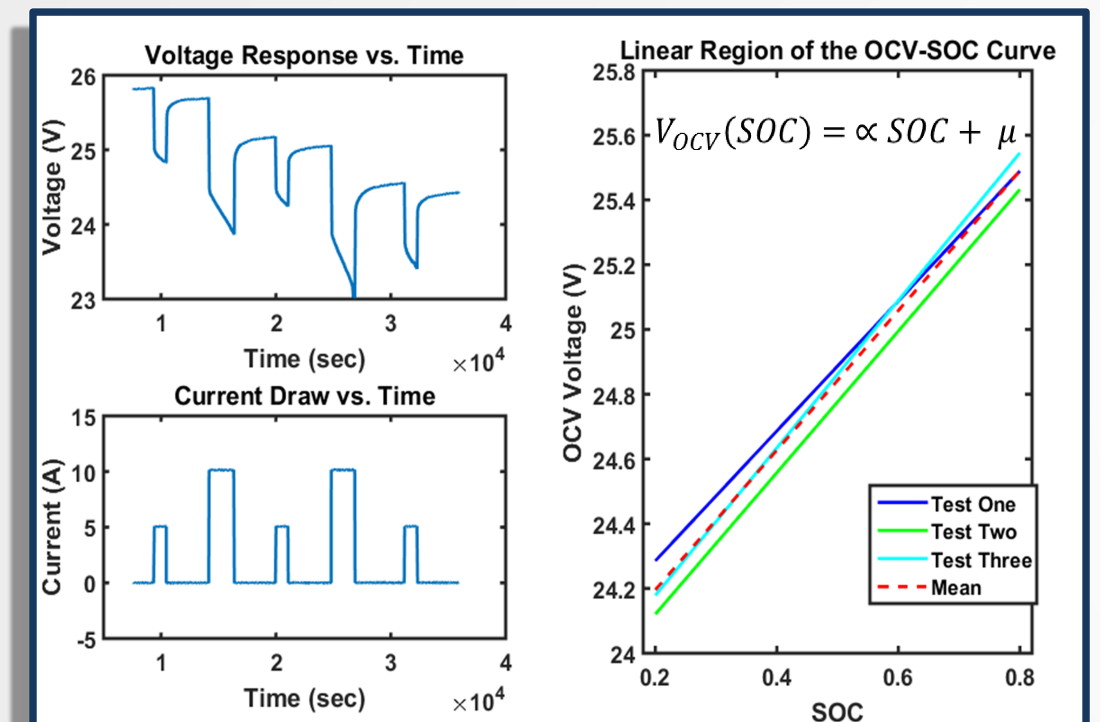


$$\begin{pmatrix}\dot{V}_{CT}\\ \dot{SOC}\end{pmatrix} = \begin{pmatrix}-\tau_{CT}^{-1} & 0\\ 0 & 0\end{pmatrix}\begin{pmatrix}V_{CT}\\ SOC\end{pmatrix} + \begin{pmatrix}C_{CT}^{-1}\\ -Q_0^{-1}\end{pmatrix}(I(t))$$

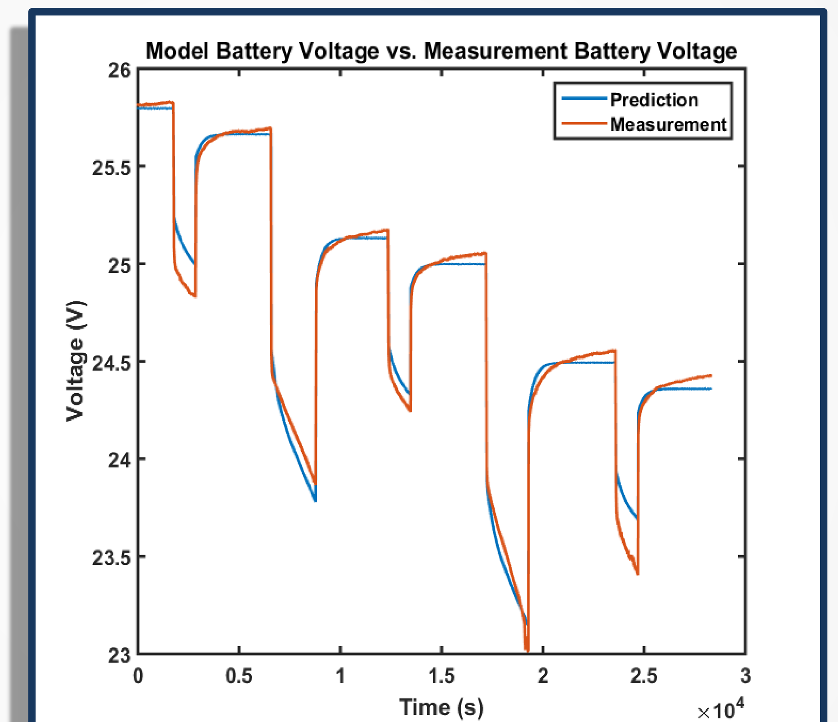
$$V_L(t) = \begin{pmatrix}-1 & \alpha\end{pmatrix}\begin{pmatrix}V_{CT}\\ SOC\end{pmatrix} + (-R_{int})(I(t))$$

$$V_{LOAD}(t) = V_L + \bar{\mu}$$

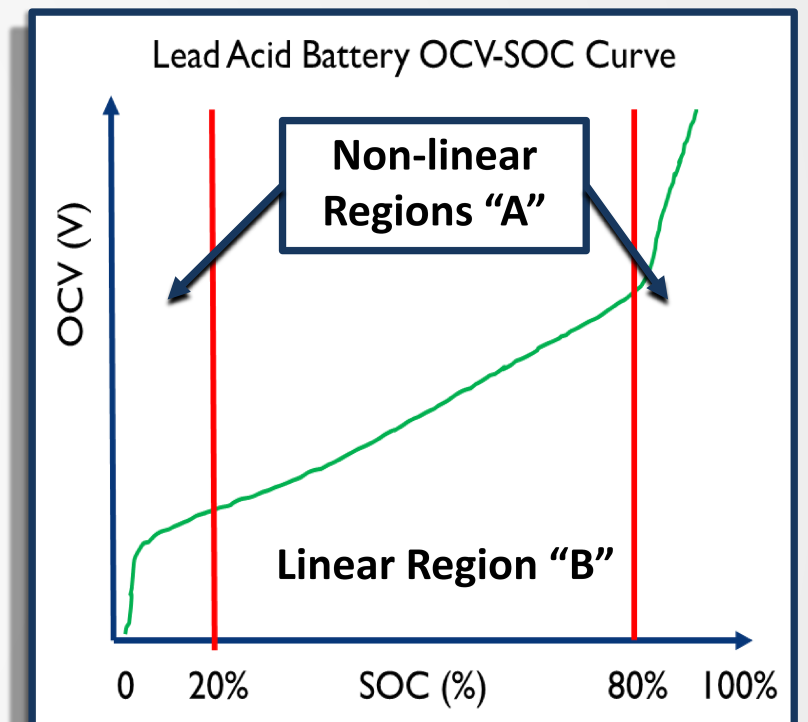
Modeling



Characterization



Parameterization



Algorithm Design

Estimator A: Coulomb Counter

$$SOC = 1 - \frac{1}{Q_0}\int_0^t I(t)dt$$

Estimator B: Kalman Filter

Prediction:

$\hat{x}_{k|k-1} = A\hat{x}_{k-1|k-1} + Bu_{k-1}$ — Estimated State

$P_{k|k-1} = AP_{k|k-1}A^T + \tilde{Q}$ — Estimated Covariance

$\tilde{Q} = diag(\sigma_{V_{CT}}^2, \sigma_{SOC}^2)$ — Process Noise

Correction:

$K_k = P_{k|k-1}C^T\left(CP_{k|k-1}C^T + \tilde{R}\right)^{-1}$ — Kalman Gain

$\hat{x}_{k|k} = \hat{x}_{k|k-1} + K_k\left((y_k - \mu) - (C\hat{x}_{k|k-1} + Du_k)\right)$ — Updated State

$P_{k|k} = (I - K_kC)P_{k|k-1}$ — Updated Covariance

$\tilde{R} = \sigma_{Sens}^2$ — Measurement Noise

Charge Estimation

The Wheelchair Platform

Wheelchair Specifications

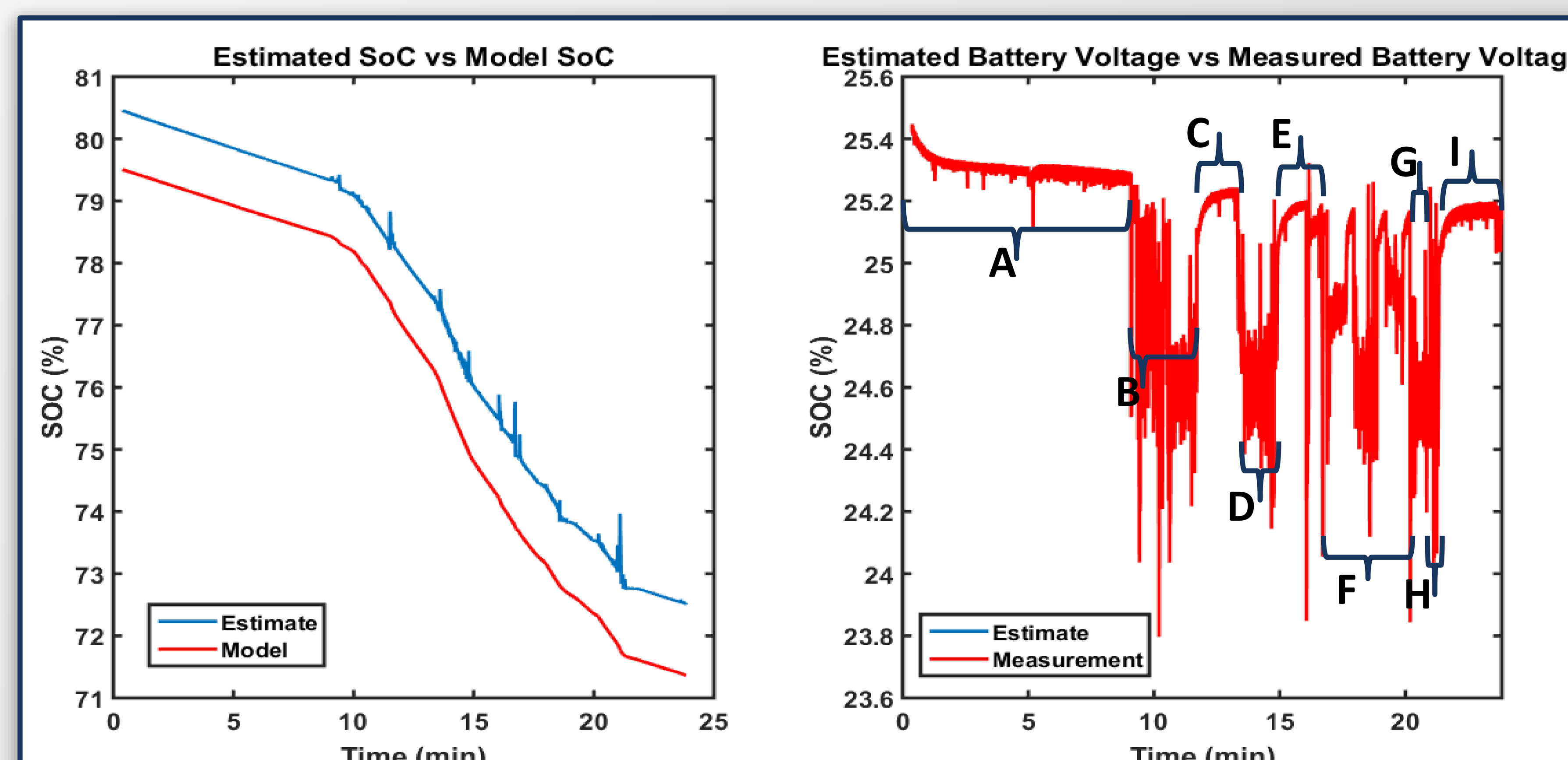
- Electric wheelchair retrofitted with an onboard computing system running ROS, the Robotic Operating System
- LiDAR, ultrasonic range finders and a webcam for perception
- Magnetometer array for indoor localization and GPS for outdoor localization
- Custom power system to ensure precise energy usage estimates to prevent stranding and allow for efficient path-planning
- Multi-tiered safety system to ensure the user's safety even if part of the system fails

The Semi-Autonomous Electric Wheelchair Platform

State of Charge Estimator Results

Wheelchair Path

A. Rest
B. Long hall
C. Rest
D. Short hall
E. Rest
F. Start-stop long hall
G. Spin in place
H. Enter doorway
I. Rest



Future Work and Expansion

Using the State of Charge estimation algorithm, develop a warning system to predict if a user can return to their charging point based upon the path traveled from the charger to their present location

Develop another estimator to track the battery parameters with time to account for battery aging and overuse damages to improve the overall State of Charge estimator

For autonomous and semi-autonomous wheelchairs, develop energy-efficient path-planning algorithms to conserve energy and maximize electric range