ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY BOARD

Will Anderson
Advisor: Dr. Brian Huggins

BRADLEY University
AGENDA

• Introduction
• Problem Statement
• Engineering Efforts
• Future Work
• Questions
• References
INTRODUCTION
PROBLEM BACKGROUND

• Battery dependency at an all-time high
• Need to use batteries at maximum efficiency
• Two most common battery capability metrics:
  – State of Charge (SOC)
  – State of Health (SOH)
PROBLEM BACKGROUND

• State of Charge (SOC):
  – A metric that reports percentage of energy remaining as compared to maximum energy\cite{1}
  – Multiple established methods of calculating SOC:
    • Coulomb Counting
    • Open Circuit Voltage lookup table
Problem Background

• State of Health (SOH):
  – Currently a more complex and uncertain method
  – Goal is to inform the user of overall condition and performance capabilities, and to warn of catastrophic failure
  – Many proposed SOH solutions require bulky and expensive equipment
  – Not viable for most Battery Management Systems
PROBLEM STATEMENT

A lightweight, compact, low power, and inexpensive solution must be found for a real-time SOH monitor to be attached to a deployable battery.
REVIEW OF EXISTING LITERATURE

• Potential SOH Methods\textsuperscript{[2]}:
  – Linear Approximation
  – Single Cell Impedance
  – Weighted Average
  – Log Book Function
  – Electrochemical Impedance Spectroscopy (EIS)
REVIEW OF EXISTING LITERATURE

• EIS:
  – Established for laboratory experiments\textsuperscript{[3]}
  – Basic Principle\textsuperscript{[4]} is to excite electrochemical cell with sinusoidal signal and measure the response
  – Linearity of the system means sinusoidal input will yield approximately sinusoidal output
EIS offers wealth of battery information[5]:

- Reaction mechanisms
- Change of active surface area during operation
- Separator Evaluation
- Possible corrosion processes

Our use is to generate frequency response and Nyquist plots
Review of Existing Literature

- Battery health degradation tracked by outward shifts in the curvature over time

Figure 1: Frequency Response and Nyquist Plots

[Image of Frequency Response and Nyquist Plots]
PROBLEM SOLUTION

• EIS determined to be most effective solution

• Proper implementation aims to\(^6\):
  – Enhance accuracy of SOC and SOH measurements
  – Fine tune individual cell balancing
  – Extend discharge and shorten charge cycles
  – Provide second life benefits
PROBLEM SOLUTION

- Sandia National Laboratories (SNL) has developed “EIS Board”
- Capable of performing two different EIS Techniques

Figure 2: High Level EIS Board Block Diagram
ENGINEERING EFFORTS

Design
DESIGN GOALS

• EIS Board intended to be capable of implementing two different EIS techniques
  – Method 1: “Pseudo EIS”
  – Method 2: “True Impedance Spectroscopy”

• My goal was to write all of the firmware for these methods

• Current board hardware is only capable of Method 1
DESIGN GOALS

• Efficient firmware was written for:
  – UART Communication to Laptop
  – ADC, LCD, Timer, GPIOs
  – Initial SPI and I2C Communication to EIS Hardware
EIS METHOD 1: “PSEUDO EIS”

Figure 3: EIS Board Block Diagram for EIS Method 1
EIS METHOD 1: “PSEUDO EIS”

- Battery excited by square-wave current pulse
- Voltage response is measured
- Fourier Transform of both waveforms
- Complex impedance response calculated
- Filtering by digital signal processing
- Nyquist Plot graphed
- Track deviations over time

Figure 4: EIS Method 1 Software Flow Chart
EIS METHOD 2: “TRUE IMPEDANCE SPECTROSCOPY”

Figure 5: EIS Board Block Diagram for EIS Method 2
EIS METHOD 2: “TRUE IMPEDANCE SPECTROSCOPY”

• Utilizes impedance converter/network analyzer AD5933 [7]
  – With help from the AD5174 digital rheostat [8]
• Allows for excitation of load by sinusoidal voltage at known frequencies
• Performs on-board Fourier transform with DSP engine
• Returns real and imaginary impedance values at known frequency
AD5933

- Impedance Converter
- Network Analyzer
- Frequency Sweep Generator
- 12 bit ADC
- DSP Engine

Figure 6: Functional Block Diagram of AD5933 [7]
EIS METHOD 2: “TRUE IMPEDANCE SPECTROSCOPY”

Figure 7: EIS Method 2 Software Flow Chart
ENGINEERING EFFORTS

Experimental Results
EIS METHOD 1 RESULTS
EIS METHOD 1 RESULTS

Figure 8: Experimental vs Theoretical Data [9]

1 Results

Current Pulse

Voltage Response

Theoretical Data
EIS METHOD 1 RESULTS

\[ Z(\omega) = \frac{U(\omega)}{I(\omega)} = \frac{U_0}{I_0} \cdot e^{j\phi} \]

\[ Z(\omega) = |Z| \cdot e^{j\phi} = R_{real} + j \cdot R_{img} \]

Where:
- \( U \) represents the FT of voltage response
- \( I \) represents the FT of excitation current
- \( Z \) represents impedance response

Figure 9: Fourier Transform of Experimental Data [4]
FUTURE WORK
FUTURE WORK

• Further research and testing on DSP algorithms for EIS Method 1
• Second version of EIS Board needed
• Firmware for EIS Method 2 completion
• Test EIS Method 2 on power supply for proof of concept
• Test EIS Method 2 functionality on batteries
• Collect data and analyze the results
FUTURE WORK

• Create database of battery health “fingerprints” to track changes in health over time

Figure 10: Estimated Nyquist Plot for Varying SOH \(^{10}\)
QUESTIONS?
References


