Using a Custom Electrochemical Sensor with Bluetooth Capability in the Field

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Problem Statement

Current lab-grade electrochemical sensors (aka potentiostats) are bulky, expensive, and require specialized lab setups. Along with this, there is a need for wireless technology in these sensors for use in environmental monitoring, wearable devices, and medical diagnostics. To solve this problem, we use the Texas Instruments LMP91000 analog front end in combination with a SiLabs EFR32BG24 microcontroller, which supports Bluetooth 5.3. Bluetooth connectivity allows for the sensor to be remotely deployed in the field, reducing complexity of universal monitoring systems. This sensor had already been developed, and introductory validating experiments were conducted, but it has not been tested in the field on a variety of chemical solutions. To compare the large amounts of data generated by the sensor, it will be necessary to utilize or create an application that can compare known good lab-grade sensor data to data from this sensor for validation.

Performance Validation

- Test and revise the sensor platform to ensure experimental results for cyclic voltammetry (CV), square wave voltammetry (SWV), differential pulse voltammetry (DPV), and chronoamperometry (CA) are comparable with that of lab-grade equipment.
- Solve hardware and software issues that arise to allow for the chemistry department to reliably run experiments.
- Ensure that experimental waveforms resemble those taken with professional equipment in the lab (seen below in figures 1 and 2).
- Create a custom Python app called Chemalyzer to analyze waveform characteristics and compare data qualitatively and quantitively.

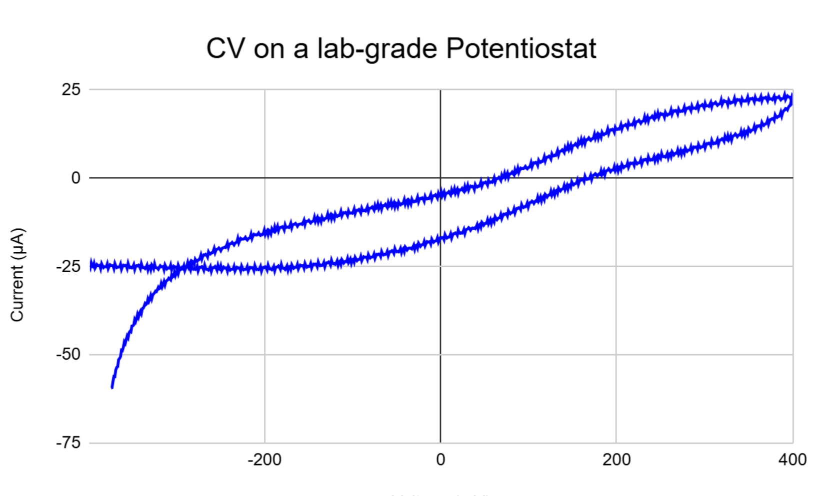

Figure 1: CV waveform from a lab grade Sensit Smart PalmSens potentiostat

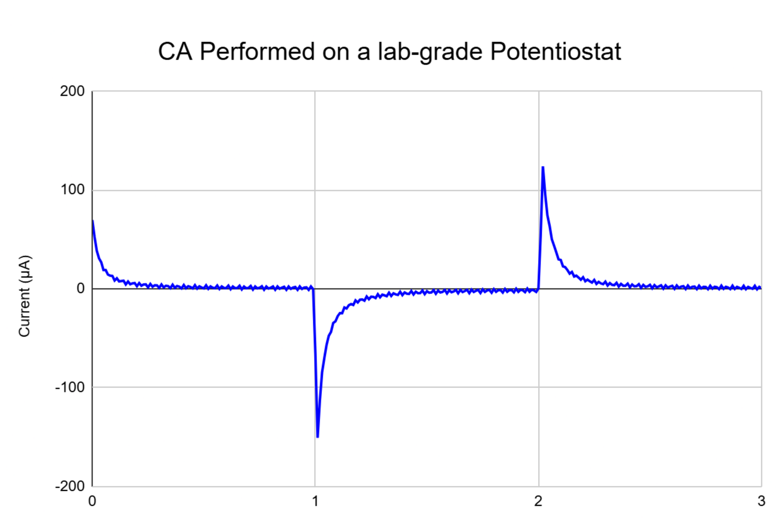

Figure 2: Multilevel CA waveform from a lab grade Sensit Smart PalmSens potentiostat

Electrochemical Experiments Performed

- CV, CA, and DPV using commercial screen-printed electrodes in 5mM ferrocyanide, 5mM ferricyanide, 0.1M KCl solution (aka ferro-ferri)
- CV and CA using commercial screen-printed electrodes in pH 6.6 Phosphate Buffered Saline (PBS) buffer solution

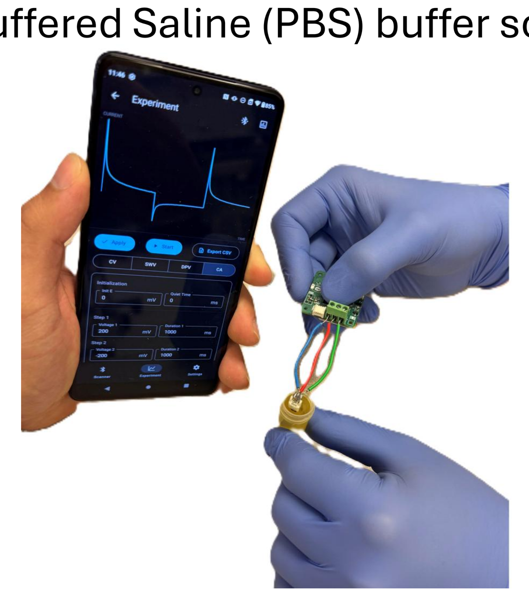

Figure 3: Experimental setup with mobile app

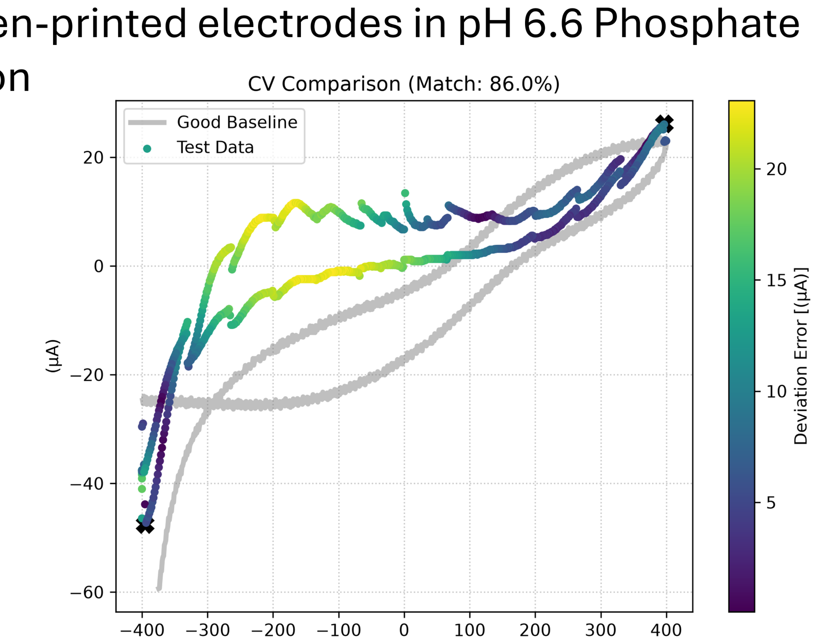

Figure 4: Comparison results from Chemalyzer app

Design Challenges

Due to the LMP91000 utilizing a virtual ground reference, the analog-to-digital-converter (ADC) must take readings relative to this virtual ground waveform. This detail was missed in the last design, leading to erroneous experiment waveforms.

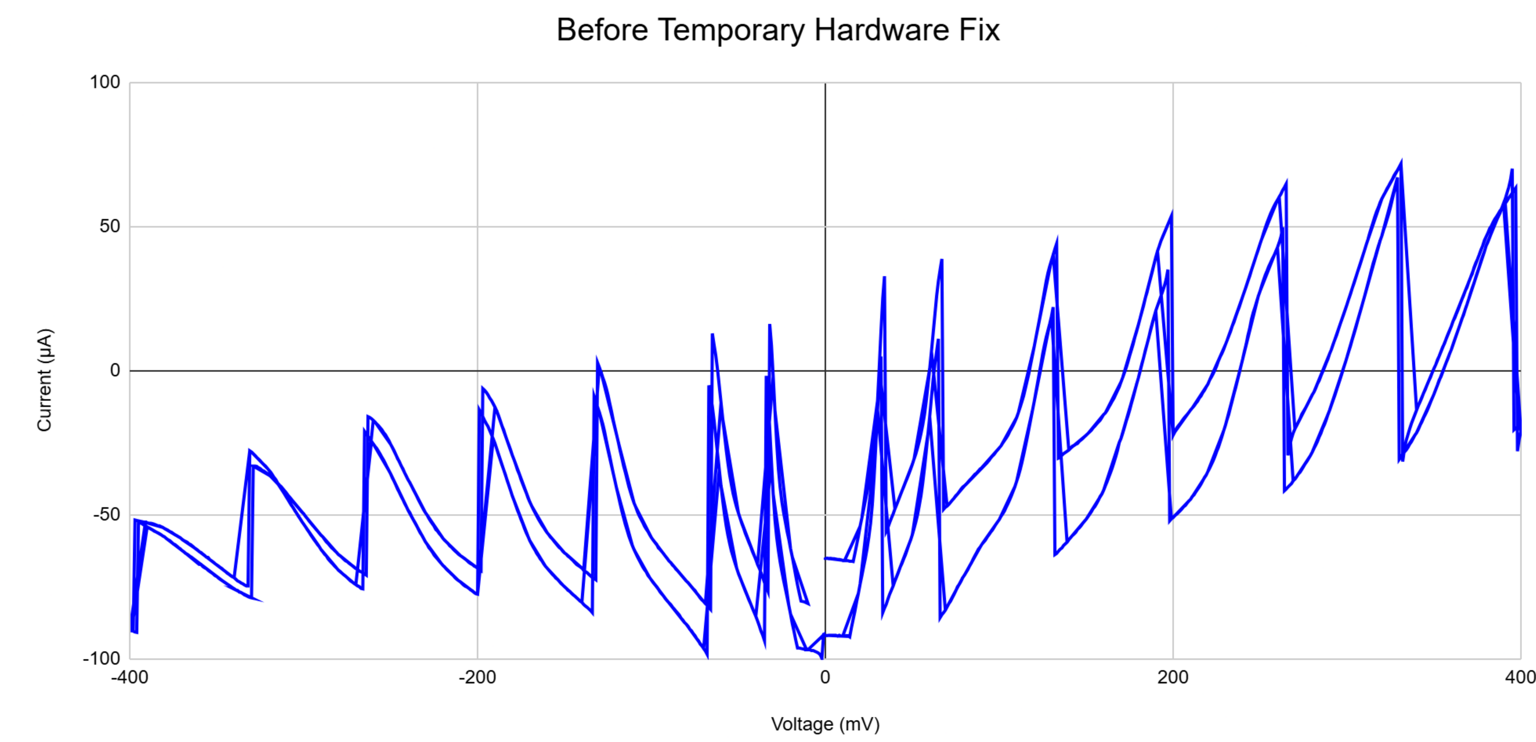

Figure 5: CV experiment from -400mV to 400mV without the hardware fix, poor data quality

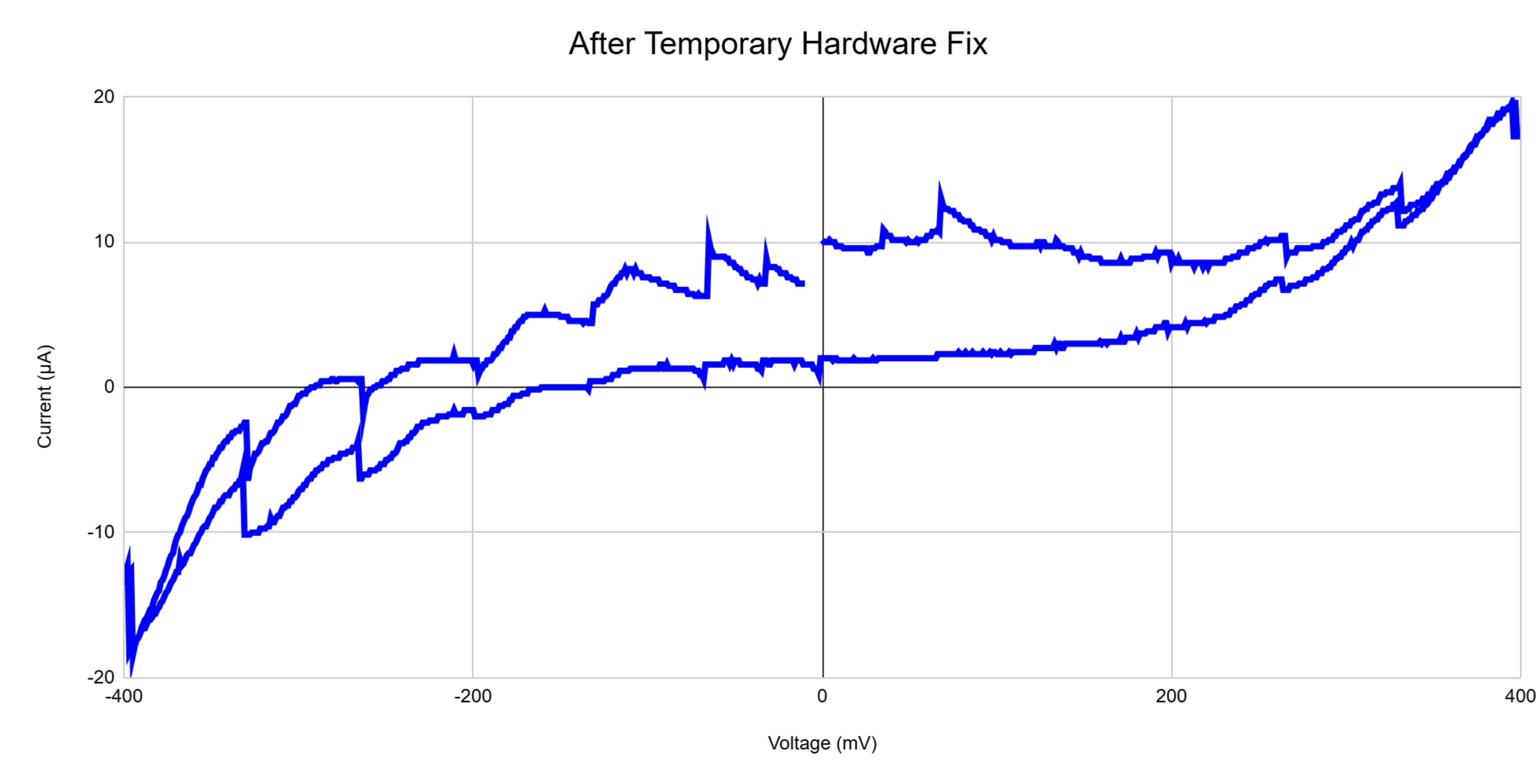

Figure 6: CV experiment from -400mV to 400mV with the hardware fix, smoother and more accurate data

PCB Redesign

Due to the missing virtual ground connection, a hardware revision was necessary. Since we had an opportunity to add features, we added an interrupt line for the inertial measurement unit, a low frequency crystal oscillator, and changed trace routing for better shielding from electromagnetic interference.

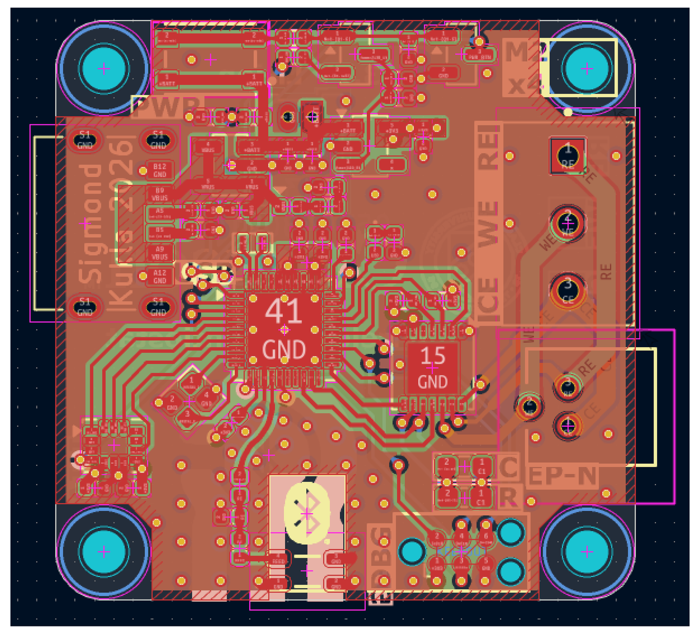

Figure 7: Electrical design of revised PCB

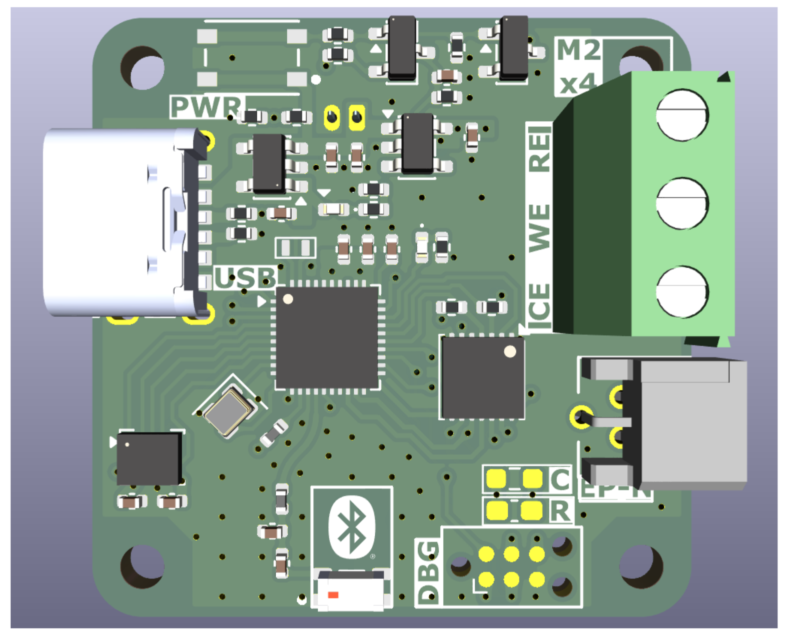

Figure 8: 3D rendered view of revised PCB

Comparing the Data

The data from the lab-grade Sensit potentiostat was compared to data from our potentiostat qualitatively and quantitively. The qualitative data analysis involves analyzing the shape profile of the data and ensuring that both experiments contain the same characteristic features. Quantitively, the data was analyzed using a custom Python script that provides standard deviation and waveform characteristic values.

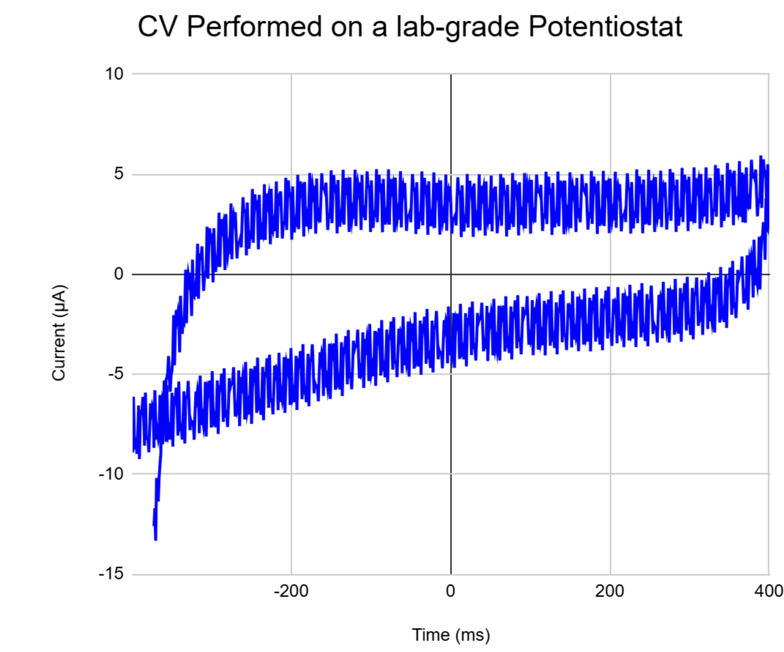

Figure 9: CV from 400mV to -400mV with a 100mV/s step rate in pH 6.6 PBS

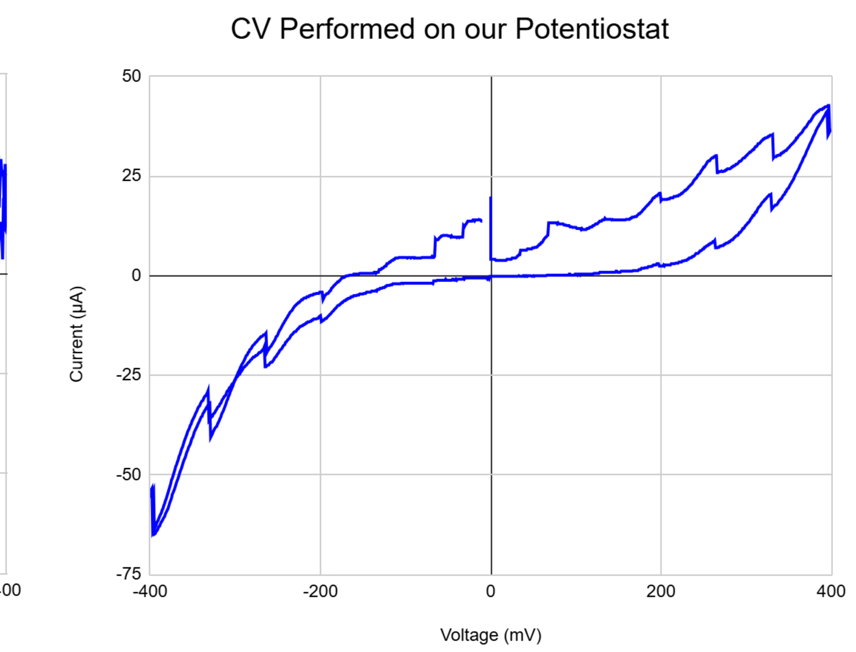

Figure 10: CV from 400mV to -400mV with a 100mV/s step rate in pH 6.6 PBS

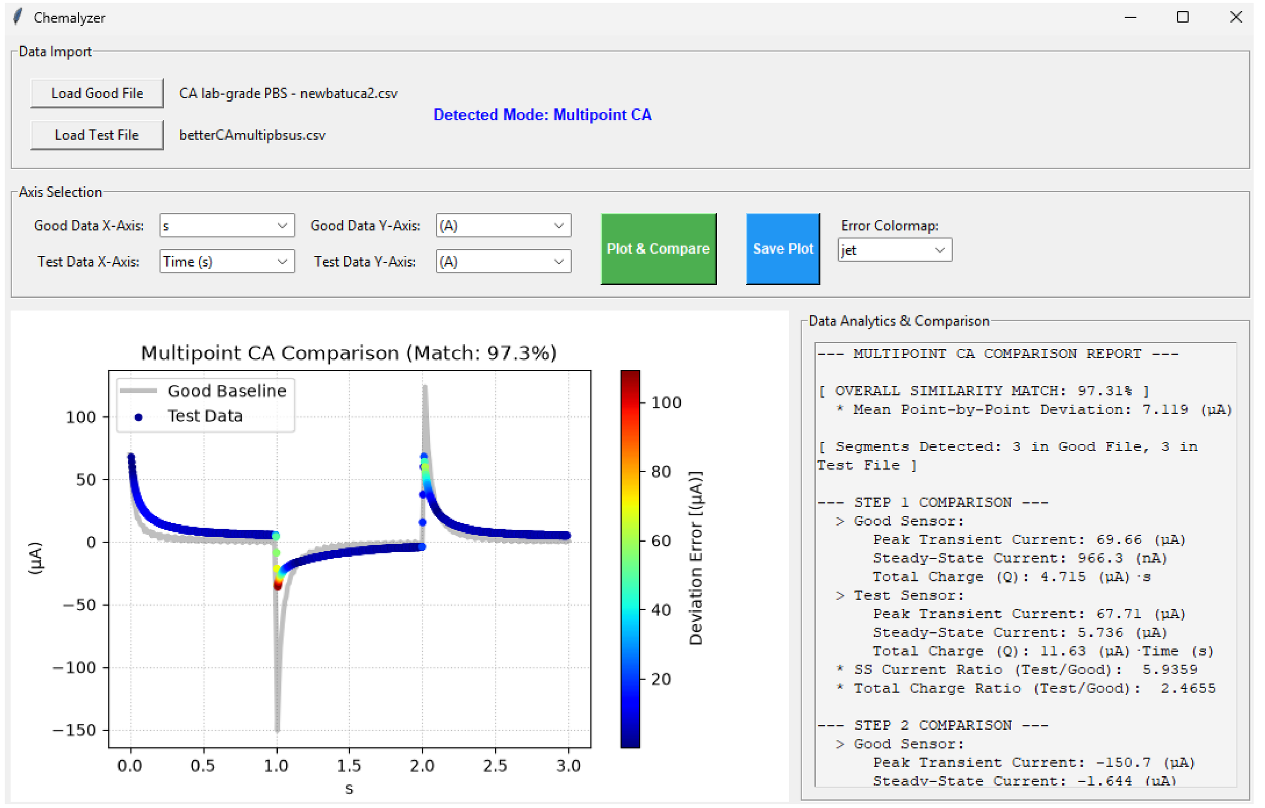

Figure 11: Interface of open-source Chemalyzer application

Further Applications and Improvements

Although the PCB redesign was completed and new boards were ordered, they have not been assembled. Further validation must be performed to ensure the data is more accurate than the temporary fix made on the current revision. Calibration curves should be generated for different solutions in different experiments to increase the accuracy of the sensor. Once this is completed, Chemalyzer can be used to ensure that the new design is comparable to lab-grade potentiostats.

Acknowledgements

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Kukla, Sigmond, et al. "Lessons learned from designing a wireless universal electrochemical sensing system." *2025 IEEE 16th Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON)*, 22 Oct. 2025, pp. 0143–0149, https://doi.org/10.1109/uemcon67449.2025.11267680.

Hoilett, Orlando S., et al. "Kickstat: A coin-sized potentiostat for high-resolution electrochemical analysis." *Sensors*, vol. 20, no. 8, 23 Apr. 2020, p. 2407, https://doi.org/10.3390/s20082407.

Chemalyzer   Firmware/PCB   Mobile App