NDnano
Notre Dame Nanoscience and Technology

NDnano Summer Undergraduate Research
2025 Project Summary

1. Student name & home university:

Vanessa Utama, University of Notre Dame

2. ND faculty name & department:

Dr. Kaiyu Fu – Department of Chemistry and Biochemistry, College of Science
Dr. Jingcheng Ma – Department of Aerospace and Mechanical Engineering, College of Engineering

3. Summer project title:

"Development and Manufacture of a Portable Potentiostat for Multi-Channel Electrochemical-Based Bioanalysis"

4. Briefly describe new skills you acquired during your summer research:

This summer, I learned how to use KiCad, and made my first printed circuit board (PCB) design! I also learned how to program a new microcontroller (ADuCM355) in C, configuring internal components including a digital-to-analog converter, potentiostat, and trans-impedance amplifier, and programming a timer interrupt. Once the PCB was printed, I learned how to solder small integrated circuit components using solder flux and solder paste.

5. Briefly share a practical application/end use of your research:

A biomedical device that is portable while still allowing for multi-marker analysis may revolutionize outpatient care by enabling patients to perform simple medical tests and preliminary diagnoses without needing to physically be in the hospital or doctor's office. The cost-effective nature of the selected potentiostat component in combination with the multiplexing capabilities of the device would allow those with chronic disease to save time and money on their healthcare.

6. 50- to 75-word abstract of your project:

A multiplexer is a switch that allows the user to progress through an array of inputs to select a singular output. This project seeks to integrate such a component into a potentiostat device to enable compact multi-channel bioanalysis. This was achieved by conducting preliminary testing with the multiplexer to ensure its ability to preserve electrochemical input signals, designing and soldering several PCB iterations, and programming its microcontroller functionality.

7. References for papers, posters, or presentations of your research:

[1] Chen, Y., Fu, K. X., Cotton, R., Ou, Z., Kwak, J. W., Chien, J. C., ... & Tom Soh, H. (2025). A biochemical sensor with continuous extended stability in vivo. *Nature Biomedical Engineering*, 1-14.

[2] Ma, J., Laune, M., Li, P., Lu, J., Yue, J., Yu, Y., ... & Tian, B. (2025). Airborne biomarker localization engine for open-air point-of-care detection. *Nature Chemical Engineering*, 1-13.

[3] Liu, J., Xu, Y., Liu, S., Yu, S., Yu, Z.-R., & Sze Shin Low. (2022). Application and Progress of Chemometrics in Voltammetric Biosensing. 12(7), 494–494. https://doi.org/10.3390/bios12070494

[4] Chen, Y., Zhang, X., Liu, Y., Liu, Z., Li, Z., Li, Z., Chen, X., Liu, J., Chen, Z., Mo, G., Xia, Y., & Mou, L. (2025). A Gold Nanoparticles and MXene Nanocomposite Based Electrochemical Sensor for Point-of-Care Monitoring of Serum Biomarkers. ACS Nano. https://doi.org/10.1021/acsnano.5c03194

One-page project summary that describes problem, project goal and your activities / results:

A worldwide surge in medical costs suggests the increasing significance of outpatient care and at-home diagnostic tools, in particular for those suffering from chronic illnesses who require continuous inpatient treatments. Though solutions have been proposed regarding take-home biomedical devices, several issues remain surrounding their implementation. Primarily, there lies a necessity in enabling a non-invasive method of biomarker sampling, while balancing the trade-off of designing a compact device while preserving expansive multi-channel detection. This project aims to tackle both issues with a comprehensive system incorporating biomarker detection and electrochemical analysis.

A promising method for non-invasive healthcare is exhaled breath collection. However, the intrinsically low concentrations of biomarkers in human-exhaled air (approximately around the ppt level) pose a challenge for existing electrochemical gas sensors (detecting at the ppm level). A proposed solution is found in the concentrated airborne metabolite collection abilities of the "Airborne Biomarker Localization Engine" (ABLE) device, which collects concentrated condensate samples of human breath and ambient air for electrochemical analysis.

Upon synthesis of these samples, they are fed into a multi-channel portable potentiostat; this project focused on designing that device. Our work introduces the usage of a multiplexer, an electronic switch which selects a singular analyte to process from an array of many. This selection technique decreases the device footprint while preserving its comprehensive analysis capabilities.

It was initially necessary to validate the multiplexer's functionality, in order to ensure it was able to appropriately preserve the input voltage signals of electrochemical testing. Circuit prototyping and breadboarding was done in order to determine what other components could be incorporated into the test circuit to improve performance. The following components were added: an operational amplifier configured as a buffer to better copy the signal, decoupling capacitors to provide stability at the power sources and grounds, and a low-dropout voltage regulator to provide a stable power source into the circuit.

An experimental method was devised to test this circuit. A MATLAB code was generated to allow the user to select waveform parameters and create a .csv file of all the data points for their specified wave. Once uploaded onto a waveform generator connected to the multiplexer's input, the wave is set as an input to the multiplexer test circuit, and the output is observed on an oscilloscope. The multiplexer's channel may be selected through an Arduino code. Upon conducting this electronic testing, it was revealed that the circuit adequately preserved the input signal for cyclic voltammetry (CV), an electrochemical technique, and performed better with the addition of the aforementioned components.

Upon validating the multiplexer, the focus shifted toward creating printed circuit board (PCB) designs through the software KiCad, in order to better organize and test components without the added complexity and resistance of jumpwires. A design was created, printed, and soldered, to integrate and test the multiplexer with a new power supply configuration (as shown in Figures 1 and 2).

The next step was to program a compact potentiostat and microcontroller component called the ADuCM355, as found in the EmStat Pico Module, a known and tested dual-channel potentiostat module from Analog Devices. By using solely the ADuCM355 instead of the whole module, footprint size and cost could be further reduced.

The C program that I created configured the digital-to-analog converter (DAC) within the ADuCM355 to work as a waveform generator to generate CV input waves. This input would then go into the potentiostat feedback loop, which would output a voltage to a trans-impedance amplifier (TIA). The TIA would return a current value, which would allow the user to then plot the output voltage vs. current curve. The program utilized a timer interrupt to steadily feed the DAC each point, ensuring consistent measurements along the input wave.

Though work remains to integrate the multiplexer and ADuCM355 components into a fully functioning device, the validation of the multiplexer and other work done thus far suggests a promising starting point for prototypes of this variety. When fully combined with a device such as ABLE, such a non-invasive biomedical data collection and analysis system may change the future of outpatient care forever.

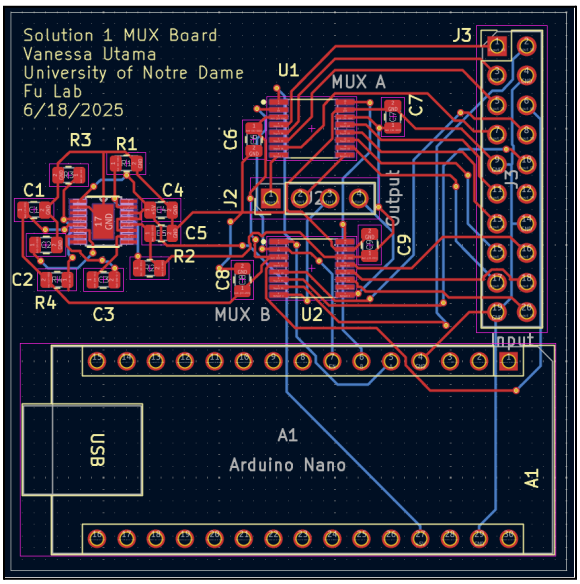


Fig. 1 – PCB Design

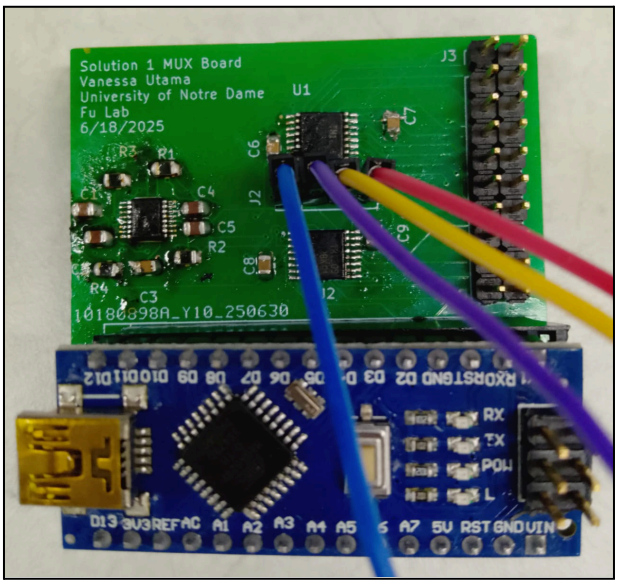


Fig. 2 – Printed Design with Components