APEGM Progress Report for: #33973 - Cameron MacGregor

Period beginning: **Apr 27, 2012** and ending: **Aug 31, 2012. (4 months)**

Submission Date:	Dec 14, 2012
Supervisor:	P.Eng. ( ), Submitted on Feb 5, 2013
Period Employer:	University of Manitoba
Job Title:	Undergraduate Researcher

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1. Give a description of the Engineering work experience you have obtained during this reporting period. Include information supporting the rest of your answers.

I worked on an NSERC and university funded summer research project on wireless pH sensors in the Nano Systems Fabrication Laboratory at the University of Manitoba. My supervisor set the general objective of the project at the start of the summer, which was to augment an existing wireless resonant pH sensor circuit with a mixed-metal oxide (MMO) electrode embedded within a hydrogel, and test its capability of detecting the presence of gaseous organic acids within a closed space.

APPLICATION OF THEORY & PRACTICAL EXPERIENCE

- My first task of the summer was to order MMO wire to act as the pH sensitive electrode for the wireless pH sensor. This was easier said than done, as MMO wire is manufactured commercially for chemical electrolysis applications; thus, there was scarce information on the pH sensitivity of commercially available MMO wire. Initially, the only information I had was from an academic paper provided to me by my supervisor before the start of the project, which showed that MMO electrodes made by a certain manufacturer in Spain have a linear sensitivity to the pH of the solution in which they are immersed. This observation was the main impetus behind my project: since MMO wire is significantly less expensive than the standard pH-sensitive electrode used for biological applications, Ir/IrO2 electrodes, it makes sense to investigate the performance of the lower-cost electrode as there are many applications which could benefit from a lower cost electrode. I found and contacted four manufacturers of MMO wire. I decided to obtain the thinnest wire possible from the geographically closest manufacturer, to minimize time spent waiting for the wire (as I only had four months to spend on this project). A company in Texas sent me a small sample of MMO wire, which arrived by the end of May.

- During the first month I collaborated with a graduate student, to get printed circuit boards (PCBs) made for my sensor. It turned out that the PCBs she designed for her project required the re-location of one trace to the other end of the board. She submitted the new design to a PCB manufacturer and asked the department technician to place the components on some of the boards once the boards arrived. These boards have a spiral PCB inductor which function as an antenna, permitting wireless measurement of electrode potential. I used the impedance analyzer to characterize the spiral inductor on one of the component-less PCBs, which involved measuring the inductance and self-resonant frequency of the coil. This information enabled me to calculate the parasitic capacitance of the coil using the LC resonant frequency equation. I also measured the performance of the PCBs populated with components. The purpose of the PCB circuit is to translate electrode potential into an LC resonant frequency that can be measured using an external interrogator coil. At the heart of the circuit lies a varactor diode whose capacitance changes with electrode potential. Previous analysis and measurements by another graduate student, who initially designed the circuit, showed that there is a linear relationship between electrode potential and measured resonant frequency. As this was a new implementation of the circuit, I verified whether this linear relationship still exists for the new circuit. Using an interrogator coil directly attached to the impedance analyzer and placed in close proximity to the spiral inductor of the PCB, I measured the change in resonant frequency of the circuit using the impedance analyzer. I initially encountered problems during these measurements, which a member of the laboratory support staff helped me resolve. It turned out that I had connected the voltage source (meant to simulate the electrode potential) backwards with respect to the varactor diode, while at the same time, the source voltage on the impedance analyzer was too high. Both were factors which pushed the diode into its nonlinear region. This experience taught me to inspect and verify every component and connection, as it had turned out that the technician had soldered the varactor diode onto the PCB in reverse. I also became aware of one practical limitation of the circuit: that I could very easily wirelessly couple too much energy into the circuit, causing it to malfunction. Once these issues were resolved, I measured the circuit resonant frequency for a series of increasing applied voltages that, using the datasheet as a reference, I was careful to keep within the linear operating region of the diode. I applied linear regression theory in order to quantify the linear correlation between applied potential and resonant frequency and calculate the slope of the data. The latter quantity was especially important because the impedance analyzer uses quantized frequencies, meaning the interval over which it can distinguish two different frequencies is finite, which imposes a limit on the accuracy with which the voltage of the electrode, and in turn the pH, can be deduced from the measured resonant frequency. I gained a practical understanding of the limitations of both the pH sensor circuit and the ability of the impedance analyzer to wirelessly measure this circuit.

- I wrote a program in MATLAB to collect data from the impedance analyzer over long periods of time. I encountered a problem whereby the internal computer of the impedance analyzer would freeze after about 20 measurements. I re-wrote the program from scratch and ran tests to determine the exact conditions which were causing the impedance analyzer to freeze, and used this knowledge to modify the program so that it could reliably command the impedance analyzer over long periods of time. This program came in handy for some of my own measurements later in the summer; a few graduate students also used the program for some of their own measurements.

- After the MMO wire arrived, I used the tools and materials in the lab to create a small electrode. This involved bonding a copper wire to a sanded edge of a small piece of MMO wire using silver epoxy which I had to cure in an oven, and painting it with an insulator to ensure that the MMO wire is the only conductive surface in contact with the solution in which it is to be immersed. I initially used clear nail polish as the insulator; within a few weeks the nail polish began to flake and crack, so I used clear epoxy as the insulator in all subsequently fabricated electrodes. Electrodes made using clear epoxy turned out to have greater environmental resiliency over the entire summer.

- The next step was to test the pH sensitivity of the newly made MMO electrode. showed me how to calibrate and use a commercial pH probe to measure solution pH. Using a series of pre-made buffer solutions of varying pH, I immersed the MMO electrode, along with two reference electrodes, into a buffer solution and tracked their potential. Initially, the potential was unstable, making it hard to record any definitive value. After noticing the potential stabilizing after five minutes, I devised a consistent method of measuring the potential of the MMO electrode with respect to a reference electrode when both electrodes are immersed in a particular buffer solution. After the electrodes were removed from the solution and rinsed, I measured buffer solution pH using the commercial pH probe, and average electrode potential was plotted versus solution pH. Linear regression theory was again applied to determine the sensitivity of the electrodes to solution pH. As the data points had a highly linear correlation between potential and solution pH, I judged the MMO electrode to be Nernstian, in that its behaviour can be sufficiently approximated using the Nernst equation, a linear equation used to theoretically describe pH-sensitive electrodes. Before I began the experiment, however, suggested I use a commercial glass Ag/AgCl reference electrode, which is considered to be a reliably stable electrochemical reference electrode, thereby permitting the best possible measurement of the MMO electrode potential without the distortion that could be caused by the drift of a less stable reference electrode. Even though the MMO potential with respect to the glass electrode was found to be highly linear, it was necessary to also measure the MMO potential with respect to a commercial bare Ag/AgCl reference electrode, which is better suited to integration into the kind of sensor I wanted to build. Measurements of MMO potential using the bare reference electrode exhibited greater drift than the measurements which used the glass electrode as reference. Because of this, I decided to investigate how the pH-sensitive MMO and Ag/AgCl reference electrodes operate. I found that the Ag/AgCl reference changes its potential according to the chloride ion concentration in solution, so if the Cl- ion concentration is not constant among the buffer solutions, potential measurements will have diminished accuracy. I obtained and read the datasheets of all the buffer capsules which were used to make the buffer solutions, and found that none of them used chloride ions to generate and maintain the shift in pH, indicating that the Cl- ion concentration of the buffer solutions was probably not the culprit behind the extra drift in measured potential. brought up the possibility of making my own reference electrodes, since she was using the same kind of reference electrode and was also facing difficulty due to reference electrode drift. So I helped and her summer undergraduate student fabricate and test Ag/AgCl reference electrodes made from silver wire. These electrodes turned out to be less stable than their commercial counterparts; in fact, we found that when we applied part of the treatment process to the commercial Ag/AgCl electrode, its stability improved. Thus, I opted to use the commercial reference electrode in my sensor. I applied circuit theory in order to quantify the combined internal resistance of the MMO electrode and commercial bare Ag/AgCl reference electrode. I connected these electrodes to the PCB and measured the resonant frequency as I placed the electrodes in different buffer solutions. I applied linear regression theory to the data to obtain a linear fit between pH and resonant frequency.

- The other major component of my summer project was absorption via a hydrogel. The idea behind the hydrogel is that it may permit detection of food spoilage without the requirement of direct electrode contact with food, thereby minimizing chemical interaction between the food and the electrode. Since hydrogel is essentially liquid water held solid using a molecular scaffolding, my supervisor and I reasoned that ordinary water would be a suitable substitute for hydrogel as far as its absorptive properties are concerned. So, using the guidance of my supervisor, I designed, scheduled, and conducted experiments to demonstrate the diffusion of a gaseous organic acid, vinegar, into deionized water, and measure the change in pH of the deionized water using an immersed commercial pH probe, and the change in potential of an MMO electrode and commercial bare Ag/AgCl reference electrode, both immersed in the deionized water. Once I could establish that vinegar can lower the pH of nearby water within a closed environment, and once I refined the experiment for demonstrating this, I repeated the experiment three times, each time consisting of two control tests and one non-control test where the pH and voltage were tracked over a six hour period, totalling 18 hours per experiment. This was done in order to establish the repeatability of the experiment.

- To create the final sensors, my supervisor asked me to create a dam on the PCBs which would hold the electrodes in place and allow the hydrogel to set and remain within the dam, thus fully enveloping the electrodes in the hydrogel. I measured the available room on the PCBs for such a dam, and measured the electrode length and thickness in order to determine the dimensions for the dam. I selected hot melt glue as the dam material, and built a mold for the damn using the dimensions I determined earlier, out of cardboard coated with silicone, as I found that silicone was the only material on hand which does not stick to hot melt glue. Noting the polarity of the varactor, I soldered the electrodes to the PCB solder pads, carefully aligned the electrodes, placed the mold over the electrodes and carefully poured the hot melt glue into the mold, pushing it down with a wet finger, as early tests with the mold showed that the viscosity of the hot melt glue prevents it from fully enveloping the electrodes on its own. I made three of these sensors, two of which were wireless. The third was made on the back of an empty PCB to accommodate a different kind of reference electrode (Nafion coated Ag/AgCl) which had obtained later in the summer, since I was unsure of how it would react to the hydrogel. Once the dams were set, I met with a professor from a different department whose research involves hydrogel, to get him to cast hydrogels into each of the three sensors.

- I then ran two tests on these sensors: the same water/vinegar absorption test as before on two of the sensors, and a new test to see if the sensor has any sensitivity to varying levels of CO_2. For the vinegar absorption test, I placed the incomplete (nafion reference) sensor and a complete sensor into a sealed container along with water and tracked their respective potential and resonant frequency in two six hour periods while water was placed beside the sensors within a closed container, and during one six hour period where vinegar was placed beside the sensors. The CO_2 absorption test required guidance from a postdoctoral lab member who showed me how to operate the CO_2 flow chambers in the chemistry building on campus. I obtained permission to use a second impedance analyzer that was on loan to our lab to take it to the chemistry building in order to measure the resonant frequency of the sensor. The postdoctoral lab member showed me how to control the flow and concentration of CO_2, which I varied exponentially while tracking shifts in the resonant frequency.

ENGINEERING MANAGEMENT

- Whenever my work required the work of someone else, I would have to book a time with them in advance in order to be respectful of their personal time constraints. In agreeing upon a mutually convenient time and date with someone, I had to consider how long it would take for the project to reach the point where that person could apply their expertise, while simultaneously aiming to minimize the time spent on that portion of the project. For example, after I scheduled a time with the hydrogel professor to cast the hydrogel, I had to set a personal schedule in order to fabricate the electrodes, design and build the dam molds, and cast the molds on time, all of which needed to happen before the professor can cast the hydrogel into the dam.

- This research project was my own, in that I was not acting as an assistant to someone else's research project. I used my understanding of the elements within the project, combined with the input and wisdom of my supervisor, to manage the project and coordinate its phases.

COMMUNICATION SKILLS

- The single most valuable lesson I learned this summer was the importance of plotting data. I found it easy to avoid plotting newly measured data because it is such a simple task, but I soon realized its indispensible value in communicating the nature of data, and how it can provide powerful insight into the behaviour of a system.

- Effective communication with my supervisor, laboratory staff, academic staff, and students (including those outside the lab or from other labs) was absolutely essential to the success of all aspects of my project. I quickly settled into the collegial atmosphere of the Nano Systems Fabrication Laboratory and was never afraid to ask questions of my supervisor or any other available person in the lab whose expertise most closely aligned with whatever problem I was facing at the moment. Most tools, materials, equipment, and instruments within the lab are shared, and in order to respect other people's needs while trying to fulfill my own, I experienced first hand the role of communication in facilitating the successful coordination of various resources within the lab.

- I contacted various manufacturers of MMO wire via email and telephone in order to communicate my requirements, inquire about available product dimensions, and to place an order for MMO wire.

- I presented my progress on the project to Dr. biomedical research group at the University of Manitoba partway through the summer.

- I wrote a four page (approximately 3000 word) conference paper which describes the key research results of the project, and describes how I obtained those results. I cited sources that I found and read throughout the summer, since I was always trying to increase my understanding of pH sensors and pH-sensitive electrodes whenever possible. I submitted the paper to the 2013 IEEE Instrumentation and Measurement Technology Conference.

- I kept a detailed bound log book in which I recorded all thoughts, observations, and experimental data. I wrote in it every day, including days in which no work was done (writing 'no work done today'), and signing and dating to mark the end of every entry.

- I created a poster of my work and entered it in the 2012 University of Manitoba Undergraduate Research Poster Competition. My poster was displayed alongside all the other entrants for the public to see, which was a good opportunity to present my work to a general educated audience, and expose the public to my engineering work.

PROFESSIONAL AND ETHICAL RESPONSIBILITIES

- I was required to make decisions based on professional and ethical responsibilities to the public and to my employer. Half of my salary was publicly funded through NSERC, with the other half funded by the university. Since I had the flexibility (up to a certain extent) to choose my work hours, I was required to make effective use of my time out of professional responsibility towards those that were funding my work, both the tax-paying public and my employer. I was required to conduct experiments with integrity, record and report data honestly and without misleading, out of a professional and ethical responsibility towards NSERC, the university, and the IEEE. In accepting funding from NSERC, I was required to sign a personal disclosure of information consent form, which binds me to the policies described in the "Tri-agency framework: responsible conduct of research", and that a serious breach in this policy would give NSERC the right to publicly disclose my name, institution, and type of breach. Thus, my commitment to responsible conduct of research is also a commitment to uphold my employer's reputation as an institution committed to research integrity, as any unethical conduct on my part would diminish the university's reputation nationally and internationally. Additionally, working within an academic environment allowed me to continue to uphold the principles of academic integrity which I have been committed to throughout my undergraduate education. Furthermore, as a member of the IEEE, I am bound to their code of ethics, which, among other things, requires me "to be honest and realistic in stating claims or estimates based on available data", and "to credit properly the contributions of others". I applied these ethical principles, for example, while writing and submitting a paper describing my research work to an IEEE conference.

Supervisor Agrees: Cam was an excellent summer student that conducted himself very professionally

2. Please check the following options that apply:

2.1: During this reporting period, I have applied theory in:

- Analysis/Interpretation
- ✓ Project Design/Synthesis
- ✓ Testing/Verification
- Implementation

Supervisor Agrees.

2.2: I have obtained experience by:

- Studying or being exposed to existing Engineering works
- Applying Designs as part of larger systems
- ✓ Experiencing the limitations of Engineering designs
- Experiencing time as a factor in the Engineering process

Supervisor Agrees.

2.3: I was exposed to the following areas of Engineering management:

- Planning
- ✓ Scheduling
- Budgeting
- Supervision
- ✓ Project Management
- Risk Assessment

Supervisor Agrees.

2.4: I was required to make decisions based on professional and ethical responsibilities to:

- ✓ The Public
- The Profession
- ✓ The Client and/or Employer
- Co-Workers
- The Environment

Supervisor Agrees: Cam's comments are very thoughtful on this subject. He did indeed carefully conduct himself and behaved in a very professional manner.

3. Describe any activities that have improved your Communication, Teamwork, or Interpersonal Skills in the following areas:

Oral Presentations:
In early August, I presented my progress on the project to Dr. [illegible]'s biomedical research group at the University of Manitoba. This presentation allowed me to practice, and thus improve, my ability to prepare and present oral presentations.

Written Documents:
I wrote, as a lead author, a four page paper which I submitted to the 2013 IEEE International Instrumentation and Measurement Technology Conference. I gained experience communicating research findings within an academic engineering context, as I had never written an academic conference paper before.
In addition, I recorded all progress, thoughts, and experimental data, totaling over 200 bound log book pages, which I signed and dated at the end of each day. This too was something I had never done before, which helped me develop a habit of committing thoughts and results to paper as soon as possible.

Interaction with Others:
The frequent interaction I experienced with other lab members (including academic staff, support staff, graduate and undergraduate students), and on occasion staff and students outside the lab, was an opportunity to practice my interpersonal skills with people of diverse personality, cultural, and educational backgrounds.

Other:
I created a poster of my work and entered it in the 2012 University of Manitoba Undergraduate Research Poster Competition. I gained experience in graphically communicating my work to a general educated audience.

Supervisor Agrees.

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4. During this period, I had to consider the social implications of my work in the following areas:

The research I was pursuing was intended to demonstrate the potential of using a wireless resonant pH sensor to detect gaseous phase organic acids, which are produced by some foods during spoilage, without the requirement that the electrodes come in direct contact with the food, thereby reducing or removing potential chemical interaction between the electrodes and the food. One of the long-term goals in this area of research is to demonstrate the potential for eventual miniaturization and integration of the sensor into food packaging. I was aware that such a wireless sensor could one day be useful in increasing the safety of the food supply, by allowing faster and cheaper detection of food spoilage.

Supervisor Agrees.

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5. Examples of my ability to work effectively as part of a team, during this period, include:

I helped a graduate student and her undergraduate assistant with the fabrication of Ag/AgCl reference electrodes which could be used in my project, the graduate student's project, and another visiting graduate student's project. We also worked together to test the stability of these electrodes.

Supervisor Agrees.

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6. Examples of my ability to assume responsibility include:

- Managing my own time
- Designing, scheduling, and executing experiments
- Ordering and obtaining certain materials
- Writing a conference paper as lead author and incorporating feedback from coauthors
- Taking good care of expensive, sensitive lab equipment when transporting it to and from a chemistry lab

Supervisor Agrees.

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7. I have shown progress since the last report (where applicable) as follows:

Supervisor Agrees.

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8. I feel myself to be lacking in exposure to, or requiring improvement in, the following areas:

- I feel I lacked exposure to the application of theory in implementation. I did not have time to test the sensor in a real food spoilage situation by the end of the summer. Such a test would be a true application of a desired end use of the sensor.
- While I did gain some experience scheduling the application of other people's expertise into parts of the project and managing my own time, I felt that I could have done a better job of managing my time and the pacing of the project, since, towards the end of the summer, I found myself working long days and rushing to wrap up the project in time.

Supervisor Agrees: I feel Cam has been a bit hard on himself. He made excellent progress, but ran into the "normal" delays in any project with this level of complexity and uncertainty.

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9. I would like to provide the following additional, relevant information:

Supervisor: P.Eng. ( ) (First Registered:)

I make the following evaluation and recommendation regarding the progress report for this MIT:

Cam completed this work professionally and in a timely manner. He managed his time well and interacted and communicated with people very well. This project is at an early stage, but Cam proceeded at a pace that I would say is equivalent to that of a outstanding newly graduated student. He wrote an abstract on his work and it has been accepted for presentation at a conference in May 2013.

In my opinion, during this reporting period, (Apr 27, 2012 - Aug 31, 2012) (4 months), Cameron has completed an equivalent of *4* months full time engineering work experience.

Please show my comments to the MIT.