CS486C – Senior Capstone Design in Computer Science

Project Description

Project Title:	Integrated, low-power system for field measurements of tree and soil respiration
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Project Overview:

Human activities are rapidly transforming the Earth's land, atmosphere, and oceans. It is widely acknowledged that climate change—driven by rising levels of atmospheric carbon dioxide (CO_2) resulting from fossil fuel burning—threatens the capacity of our planet to support life. But, major knowledge gaps hinder our ability to accurately predict the complex interactions that will determine how ecosystems respond to, and also influence, future climate change. Improved understanding of the impacts of climate change on ecosystem health and productivity is critical for sustainable management of the Earth's resources. In this regard, forests are particularly important: forests cover about one-third of the Earth's land surface area, and play a vital role in the global cycles of carbon and water.

In the Richardson-Carbone Lab, we study carbon cycling in forest ecosystems. In a nutshell, our work seeks to understand the balance between carbon uptake (*photosynthesis* by plants) and release (*respiration* both by living and growing plants, as well as by micro organisms decomposing dead organic matter in the soil). This is important for understanding the potential net effect of forests within the overall climate change equation.

This project is motivated by the challenge of efficiently collecting the large amounts of data needed to drive this research under difficult conditions: in all seasons, away from power and Internet, and potentially some distance from the nearest road. For example, we measure plant respiration (Figure 1) by enclosing part of a tree stem with a small chamber, and measuring the rate of CO_2 accumulation within that chamber using an instrument called an infrared gas analyzer (https://www.licor.com/env/products/gas_analysis/LI-840A/). The gas analyzer is connected to a laptop computer, which reads the data from the analyzer via serial communication. Data are logged every second, and the rate of increase in CO_2 over time is proportional to the respiration rate. A typical measurement sequence takes 2-5 minutes.

The main problem with our existing respiration measurement system is that it is clunky and not particularly field-portable. For example, the laptop must be disconnected from the gas analyzer so that the instrument case can be closed to minimize the likelihood of damage while moving between forest plots. Additionally, laptop batteries often don't last for a full day of measurements in the field. The computer program—largely unchanged for 15 years—that

Figure 1. Left: Measuring tree respiration in the field (Bartlett Experimental Forest, New Hampshire). Air is pulled from the PVC chamber attached to the tree, to a portable gas analyzer. **Middle**: A portable gas analyzer. The instrument measures 9" x 6" x 3" and is powered by a 12V battery. **Right**: the increase in chamber CO2 concentration over time is proportional to the tree's respiration rate.

logs data from the gas analyzer has a poor interface and there is no way to associate metadata or notes with the measurement sequence. Finally, calculation of respiration rates must be done at the end of the day, using a separate program.

Project Vision:

What we envision is a new system, designed from the ground up, that takes advantage of recent advancements in small, low-power computers (e.g. Raspberry Pi) and wireless data transmission (e.g. Bluetooth), together with the convenience of a smartphone user interface. Briefly, the Raspberry Pi would serve as the link between a smartphone and the gas analyzer, pulling the serial data from the gas analyzer, and storing it locally. When a Bluetooth connection to a registered device becomes available, data are transferred and forwarding those data via Bluetooth to an iOS or Android smartphone. A smartphone app would plot the data in real time, allow entry of metadata (manual entry of tree or plot number; potentially also scanning of an RFID tag or QR code for identification, or using the smartphone's camera to photograph the tree or plot being measured), and allow the user to turn logging on and off and control logging frequency (e.g. from 10 Hz to 0.01 Hz).

The key features and their priorities can be summarized as follows:
Phase 0: Minimum viable product:

- Raspberry Pi or Arduino interface to gas analyzer (team will study options and recommend platform)
- Stores data locally and/or on attached USB drive. Data is retrieved manually.
- Has basic control interface (small LED display, lights, buttons, etc.) to indicate process status and control the process.

Phase 1: A product that would truly be useful:

- Adds Android or iOS app interface to manage process control. (Android/iOS decided in design phase)
- Connects to paired Pi/Arduino via Bluetooth when in range.
- Allows control of gas analyzer and shows process status, including dataset(s) collected.
- Allows meta-data annotation of datasets, e.g., time/place/tree ID. Maximally automated.
- One or more ways to retrieve data files from smartphone, e.g., mail attachment, Dropbox upload, etc.

Phase 2: Really nice features that would be lovely to have:

- Ability to visually inspect datasets on smartphone interface, e.g., see the graph in Figure 1.
- Allow scanning of QR codes or RFID tags to automatically fill in metadata for datasets.
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Other constraints:

- The entire system, including gas analyzer, air pump, battery, and computer, must fit within a Pelican 1450 case (14" x 10" x 6")

This system will be used by scientific researchers in field studies of tree metabolism and soil decomposition. This work is being carried out within the Richardson-Carbone lab at forest research sites across North America, from Arizona to Maine. The design will be shared with other scientists at research institutions around the world.

Knowledge, skills, and expertise required for this project:

As the details of the system design are finalized, the team will be expected to identify the knowledge and skills required to successfully complete the project. Beyond senior-level programming capabilities, expertise or familiarity with the following will prove useful:

⇒ the integration of hardware and software components
⇒ serial data communication
⇒ wireless communication via Bluetooth
⇒ Raspberry Pi or Arduino
⇒ mobile application development for iOS (preferred) or Android devices
⇒ graphical display of data and basic statistical calculations

Equipment Requirements:

Equipment required to build the system (gas analyzer, power, cables, Raspberry Pi, etc.) will be supplied by the client. The team can use their own mobile device for development and testing; if no such devices are available, the client will provide one.

Software and other Deliverables:

- ⇒ A functioning, low-power, lightweight, respiration measurement system that is controlled by smartphone app
- ⇒ A strong as-built report detailing the design and implementation of the product in a complete, clear and professional manner. This document should provide a strong basis for future development of the product.
- ⇒ Complete professionally-documented codebase, delivered both as a repository in GitHub, BitBucket, or some other version control repository; and as a physical archive on a USB drive.