Using Low Cost Sensors to Measure Particulate Air Pollution*

Background:

Poor air quality is a problem that affects the health of many communities, and measuring air quality can be extraordinarily important to people with health problems. In Lewisburg, PA, the high volume of truck traffic on Market Street may be leading to high levels of particulate air pollution, a known human health hazard. The Lewisburg Neighborhoods Corporation, the Mayor of Lewisburg, and a group of faculty are interested in establishing a network of 'low-cost' air pollution sensors throughout the Borough of Lewisburg to monitor air quality. These sensors measure particulate matter that is smaller than 2.5 μm (i.e., PM 2.5).

Last year, students from CEEG 340 tested two low-cost air quality sensors that were "built" with inexpensive and readily available parts. Based on their work we chose one of the sensors (Plantower) to continue working with based on its better performance. This semester we will continue this work by testing eight Plantower sensors in Lab 12, and trying to use the sensors in Lab 13. This is not a canned lab. The intention of this lab is not to repeat a procedure I am familiar with in order to teach you something. The intention is for you to help me create value by constructing low-cost sensors. Some of the Plantower sensors (each costs ~$10) may not work.

Research Questions:

- Can we use low-cost sensors to accurately measure PM 2.5?
- How can we calibrate low-cost sensors to a reference sensor to accurately measure PM2.5?
- Do the sensors pick up changes in indoor air quality around campus. We will address this question in Lab 13.

Materials:

- **Arduino Uno board or equivalent.**
  - An Arduino consists of a circuit board (or microcontroller) that can be used to run sensors and collect data. The board can be programmed by Arduino computer code, and the code must be uploaded from a computer to the Arduino board. The board can be powered through a USB cord to a computer, or through a 9V battery connection.
- **Air quality sensors.** We are using one low cost air quality sensor Plantower (http://www.plantower.com/en/). In addition, we will measure temperature and humidity with a sensor from Grove (http://wiki.seeedstudio.com/Grove-Temperature_and_Humidity_Sensor_Pro/), as temperature and humidity have been shown to affect the ability of low cost sensors to measure particulate air pollution. In addition, today we will use the TSI Optical Particle Sizer as a reference sensor. This sensor collects high quality data, but it costs approximately $15,000.
- **Particulate Concentrations:** The low-cost air quality sensors we are testing provide a *relative* estimate of PM concentration. These sensors will need to be calibrated for PM2.5 to provide accurate estimates. We will use a reference sensor (Optical Particle Sensor by TSI) to analyze the accuracy of the sensors, and to create a plan for calibration.
- **MicroSD Card Reader:** The SD card allows users to record data for long periods of time to be opened later for analysis on a computer. The card should be something smaller than 32 GB.
  https://www.amazon.com/SenMod-Adapter-Reader-Module-Arduino/dp/B01JYNEX56/ref=sr_1_1_sspa?s=electronics&ie=UTF8&qid=1525987957&sr=1-1-spons&keywords=sd+card+reader+arduino&psc=1
  https://www.amazon.com/gp/product/B00MHZ70KO/ref=oh_aui_detailpage_o00_s00?ie=UTF8&psc=1
- **Computer**: A computer will be used to load the Arduino code onto the boards. Also, the serial monitor in the Arduino sketch editor can be used to see the particulate concentrations

if connected through the USB (use ctrl-shift-m to open, or it's under tools). We won't be able to do that today, because of space in the lab.

Other materials:

- **Stopwatch**: You will want to mark the time at which each sensor starts. The Arduino will record data with the first reading being at t = 0 and you may need to know what time the first and last times correspond to.

Wiring and setup: The Arduino, sensors, and SD card (used to collect data) have already been connected for you. (I have been working on this over the past couple of weeks.)

Loading the Arduino code to the board: Go the Lab a12 Google Drive Folder (link on course website under Lab 12). Download the code for the Plantower sensor onto the computer. Copy the code file into the Arduino folder under documents on your computer.

Unfortunately, we need to install two Arduino libraries each time someone new logs onto the computers. Open the Arduino program and follow these steps to load the two missing libraries:

1. Under "Sketch" → "Include Libraries" → "Manage Libraries", write *dht* in the "Filter your search" bar. Select and install the *Grove Temperature and Humidity Sensor* library.
2. Under "Sketch" → "Include Libraries" → "Manage Libraries", write *Plantower* in the "Filter your search" bar. Select and install the *PMS Library by Mariusz Kacki*.

Now you're ready to hook up the Arduino Board to the computer with the USB cable. After it's connected, do the following using the Arduino Program:

1. Under "Tools" → "Board", make sure that "Arduino/Genuino Uno" is selected. It should be.
2. Under "Tools" → "Port", select your Arduino board. Ask Prof. Sills if you're not sure what to select here.
3. Verify the code by selecting the check mark symbol (top left corner) and wait for the code to be verified. A message will appear at the bottom of the screen that says 'Done Compiling'.
4. Select the '→' symbol (next to the check mark) to upload the code to the board. This should take a few moments, and wait until the message 'Done Uploading' appears at the bottom of the screen. Disconnect the board from the USB cable.
5. Remove the SD card from the SD shield on the board, insert the SD card into the computer, and **delete the data file "DATAOG.txt" from the SD card**.
6. Insert the SD card back into the SD shield on the board, and check with me that it's inserted properly.
7. Tell me when your board is ready, and disconnect the board from the USB cable.

Data Collection:
Data will be collected for eight Plantower sensors (four in the 8am lab and four in the 10am lab), as well as the TSI reference sensor. PM2.5 will be generated with a vape (e-cigarette) in a closed chamber. Data collection will start when the boards are connected to power after being placed in the chamber. After 60 minutes have elapsed, retrieve your board + sensor and go back to your computer. Remove the SD card from the board and insert it into the SD port on the computer. Copy the file "DATALOG.txt", and save it with a new relevant name that includes all of your last names, the name and number of your sensor. An example file name:

'Olson_Henk_Acampora_Zhan_ Plantower1.txt'. When finished copying the data file to the computer, reinsert the SD card to the sensor's Arduino shield.

Before you leave lab, open the Plantower .txt file. Since it's a .txt file, you need to open the file by first starting Excel and selection "file" → "open. Then select 'Delimited'→ 'Next', select 'Tab' and 'Comma', and select 'Finish'. All of the data should be separated by columns now instead of commas.

For the **Plantower,** the second column is PM2.5 ($\mu g/m^3$). So copy and paste the second column of data to a new sheet. In the new sheet, insert a column to the left of the PM2.5 data for time, beginning with 0. Fill in the rest of this column (time in minutes), based on the time for data collection (should be 60 minutes). You can calculate the time interval of data sampling (in units of minutes) by dividing 60 minutes by the number of data points. Highlight the time column and the $PM_{2.5}$ concentration column and create a scatter plot. **Save the file as an Excel workbook**, and upload the Excel file do the Google Drive folder.

Data Storage:
Before you leave lab, upload your file saved as an Excel Workbook with the filename in the following format: 'Olson_Henk_Acampora_Zhan_ Plantower1.xls'

Data Analysis:

1. On one graph, plot the 'Concentration vs. Time' data for your Plantower sensor and the Reference Sensor for your lab period. Prof. Sills will post the data for the reference sensor, and each lab team will post data for the sensor they set up and collected data from.
2. Compare the data from the Plantower sensor to the data collected by the reference sensor.
3. Recommend next steps for calibrating the data from the low-cost sensors. Describe challenges for and questions you have about calibration. Recommend steps that could be taken to calibrate the sensors.
4. Discuss the data quality for the low-cost sensors, and provide a recommendation for continuing work with the low-cost sensor.

Deliverables:
Memo to Dr. Sills with the two data sets (Plantower and Reference Sensor) plotted on one graph, and discussion described under Data Analysis. **One Memo per table.**

Due Date:
December 3, at the beginning of lab.