A Balloon-Borne Optical System for Measuring In-Situ PM2.5 Aerosol Concentrations

Michael Petersen, Bronson Stephens, John E. Sohl, Fon Brown

Electronics Engineering & Physics Departments, Weber State University, Ogden, UT

Abstract

A major concern for human health and wellbeing is the impact of PM2.5 aerosols and other pollutants, such as NO_2, SO_2, CO_2 and Ozone that are being released into Earth's atmosphere. The Utah Division of Air Quality (DAQ) currently makes air quality predictions that are based on models derived from ground station measurements. Little PM2.5 aerosol and gas data exist for altitudes more than a few meters above the ground and, in a sense, current air quality predictions are based on limited data. The High Altitude Balloon for Outreach and Research (HARBOR) team has paired with the Utah DAQ to develop a balloon-borne system that can measure air quality high above the ground. The new aerosol system will be light weight, low cost, and will make real-time in-situ measurements of PM2.5, NO_2, SO_2, O_3, and CO_2. It will function on HARBOR's current Multi-Sensor Array (MSA) platform. There are several studies proposed that will utilize the new sensor system. One study will measure PM2.5 concentrations as a function of altitude, revealing how high the effective PM2.5 layer extends and whether it is confined to inversion layers. Another study will investigate O_3 plumes above Great Salt Lake; where much of the O_3 in the surrounding area may be generated.

Design Overview

The Aerosol and Gas Sensor will consist of six major subsystems:

1. Multi-Sensor Array (MSA) Data Logging Computer
2. PM2.5 Sharp Cutoff Impactor
3. Intake Air Heater
4. Aerosol, Gas, Temperature, and Humidity Sensors
5. Mass Air Flow Sensor
6. Vacuum Pump

The current Multi-Sensor Array (MSA, Figure 1) system features a standard set of sensors that monitor flight dynamics and environmental conditions from inside the MSA enclosure, shown in Figure 2. These sensors allow for analysis of data events due to vibrations, and sharp changes in pressure, temperature, and humidity. Figure 3 shows how sensors and components will connect to the MSA. The MSA will also control a flow pump, heater, and infrared LEDs necessary to gather aerosol data, and store the data on a 16GB SD card.

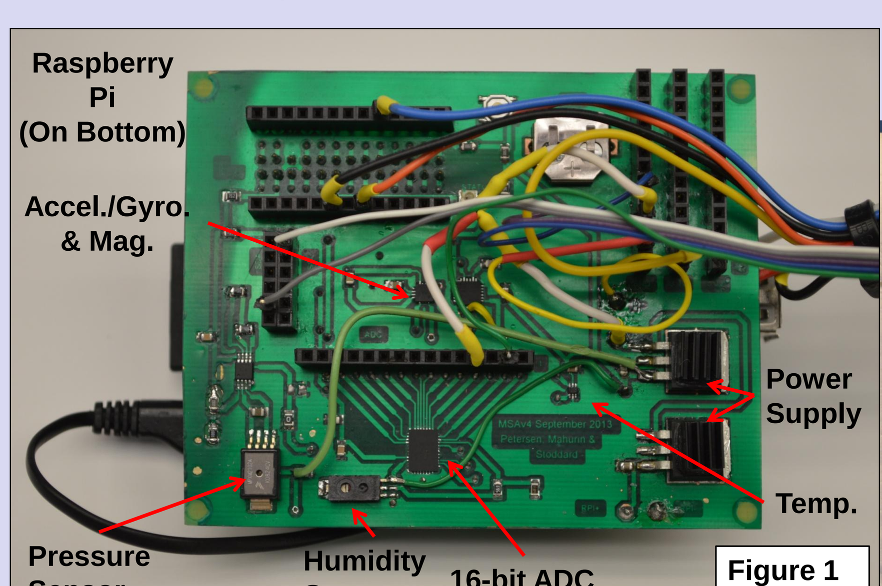

Figure 1: MSA data logging computer

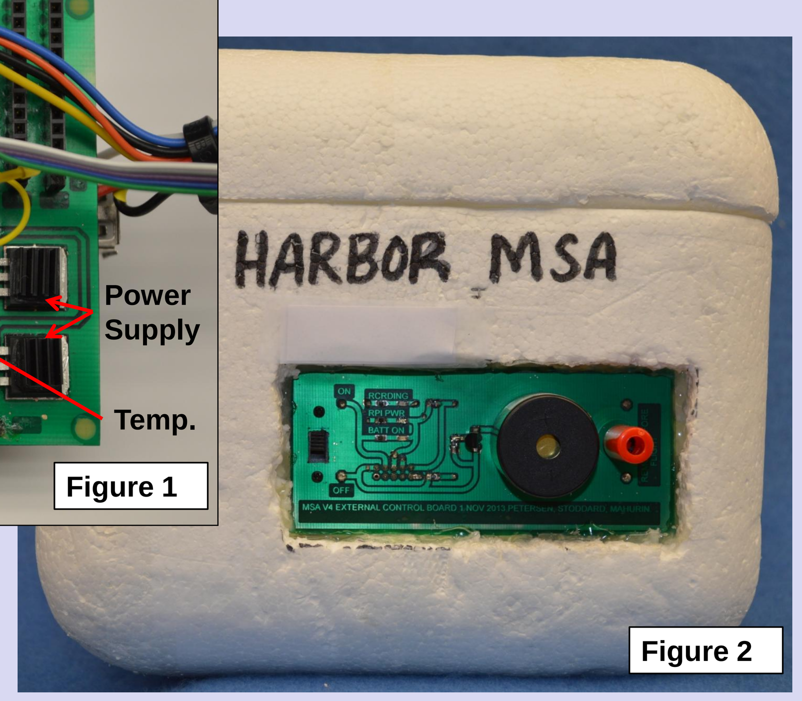

Figure 2: MSA enclosure and controls

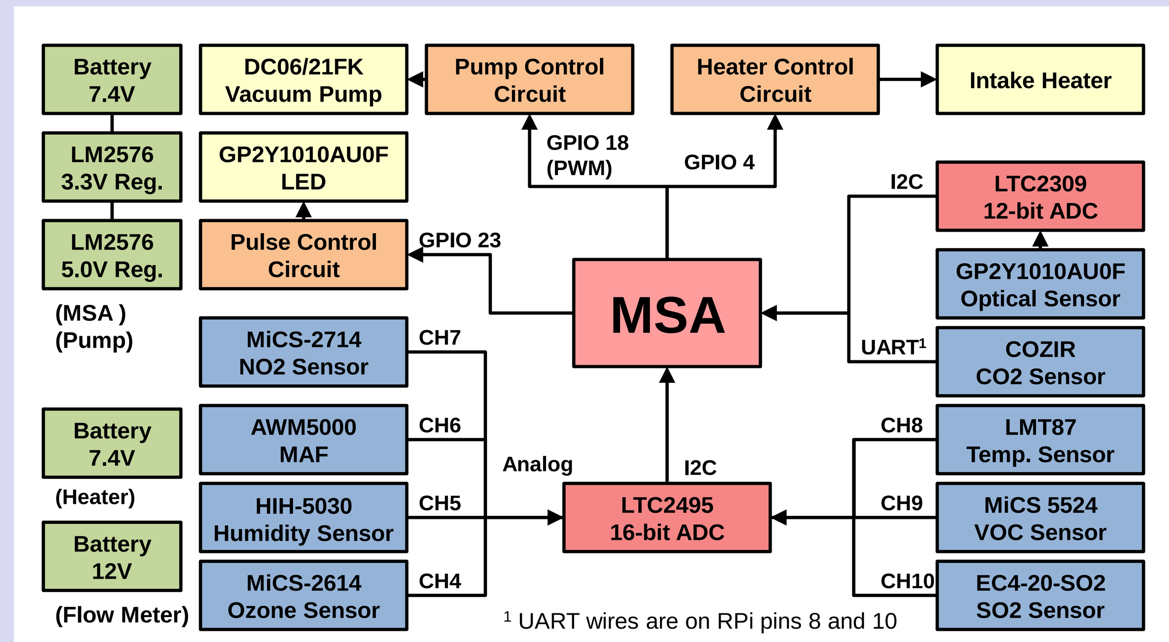

Figure 3: Aerosol and Gas Sensor Block Diagram

A PM2.5 Sharp Cutoff Impactor will remove particulates that have an aerodynamic diameter greater than 2.5 microns. An intake heater will limit humidity levels to less than 50% RH, as well as maintains an optimal operating temperature for electronics located downstream. Commercially available sensors will monitor aerosol and gas density, as well as gas composition, temperature, and humidity. A mass flow sensor will be used to maintain a 3.0 SLPM air flow; which is required to ensure the Sharp Cutoff Impactor functions properly. Finally, a 5.5 SLPM, 94mmHg max-rated vacuum pump will pull air through the system. Figure 4 illustrates how components will be arranged in the airstream.

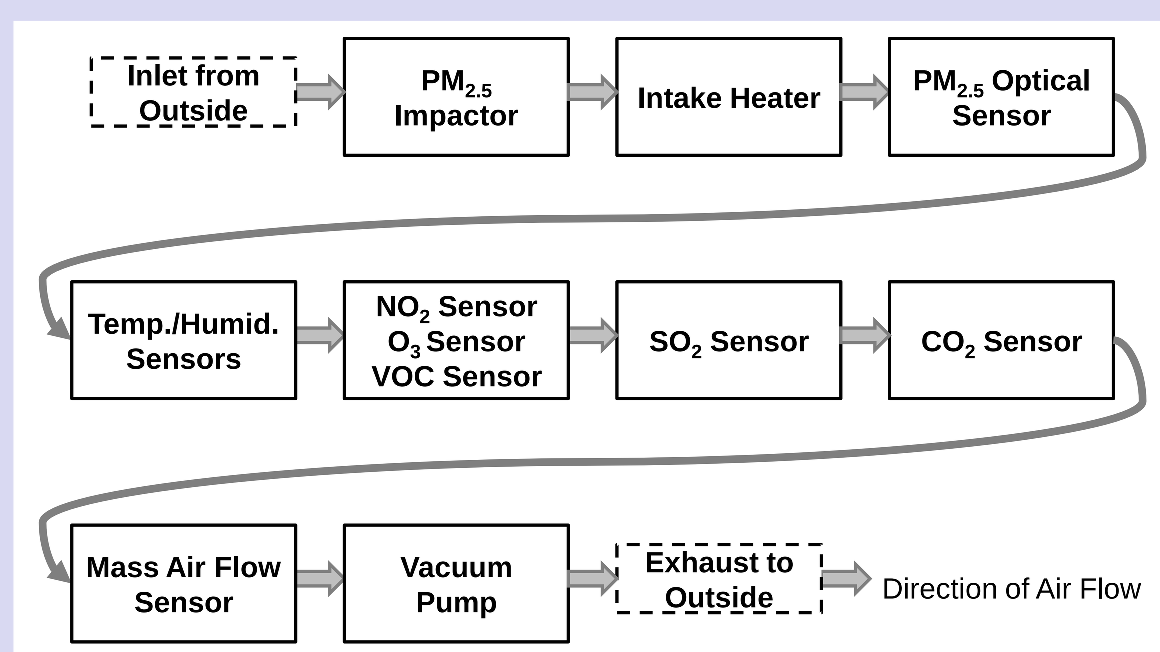

Figure 4: Aerosol and Gas Sensor Air Flow Diagram

Requirements

The Aerosol system must weigh less than 4lbs; including the MSA, batteries, enclosures, insulation, harnesses, and all electronic components. The system must operate on two 7.4V 3000mAh batteries for a minimum of 4 hours. The system must be designed to operate at temperatures near -50°C and pressures as low as 0.75mmHg. Relative humidity must be kept below 50% RH to prevent bonding of water vapor to particulate surfaces; which can alter the optical characteristics of the aerosol.

The base sample rate will be 10 Hz for aerosol data and 0.1 Hz for all other environmental data. An ascent rate, for high altitude missions, of 4 meters/second will produce a resolution of 10 aerosol measurements every 40 meters. The resolution for other environmental data will be 1 measurement every 40 meters.

Lab Testing and Calibration

A gas and aerosol sensor prototype, shown in Figure 3 below, will be tested in the Weber State University environmental test chamber as well as at the Utah Division of Air Quality test facilities.

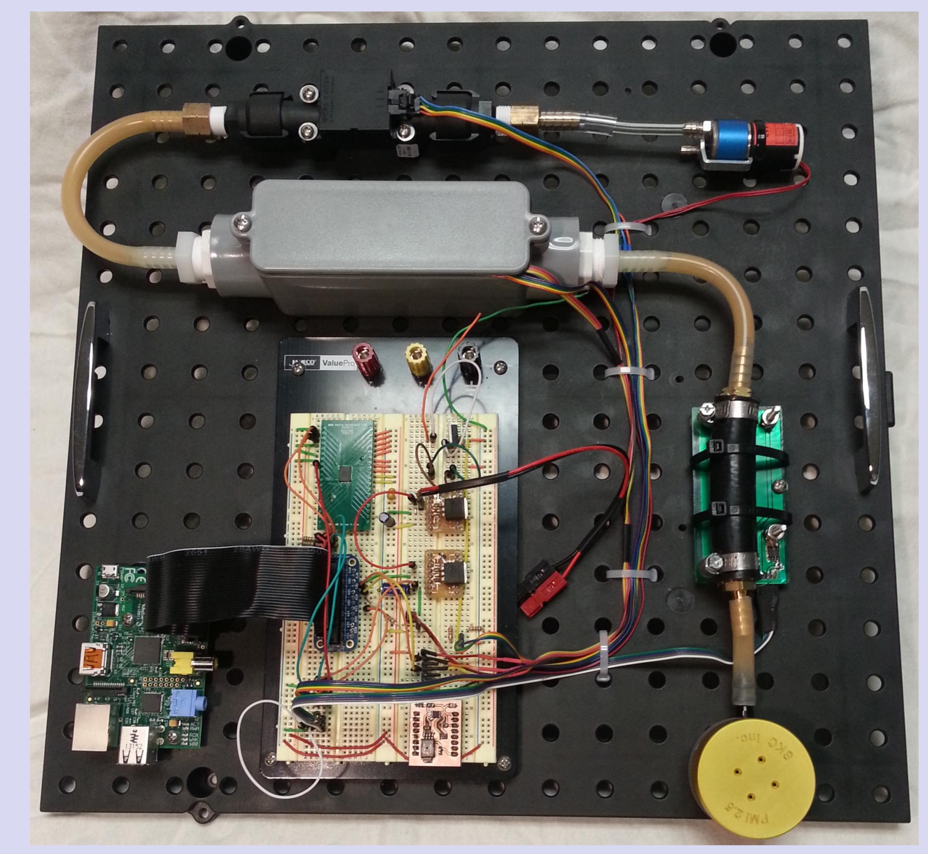

Figure 5: Aerosol and Gas Sensor Prototype

Deployment and Data Acquisition

Once the prototype passes validation testing and calibration, a flight ready package will be produced. The flight ready system will make in-situ aerosol and gas measurements above local elementary schools located near or at DAQ measuring stations. Ground data readings will be compared to those provided by the DAQ for calibration and control purposes.

Above ground measurements will be made using a moored aerostat at altitudes of 150 meters and 300 meters AGL. Other measurements will be made on low altitude balloon missions at altitudes of approximately 1.5km to 2 km AGL. Higher altitude measurements will be taken during stratospheric missions launched from the Duchesne municipal airport above the Uinta Basin, reaching altitudes of approximately 30km ASL.

Data collected on these missions will be analyzed by Weber State University researchers and archived for future reference. Data will be shared with the DAQ as well as with the Department of Atmospheric Sciences at the University of Utah. Calibrated ozone measurements will be shared with Environment Canada, a world repository for ozone data that maintains detailed world maps of atmospheric ozone concentrations.

Current Status

Our team has produced a functioning prototype that must be tested and calibrated. Air flow and heat control circuits have been tested and verified. Once we have completed initial calibration and proof-of-principle testing, a more compact and lighter weight flight version will be constructed. Initial calibration should be complete by the end of May, 2014 and initial flight tests will happen over the course of summer 2014.

HARBOR
High Altitude Reconnaissance Balloon for Outreach and Research

Acknowledgements

This project is funded in part by the Val A. Browning Foundation, the Ralph Nye Charitable Foundation, the Weber State Office of Undergraduate Research, and the Utah Chapter of the AIAA.