A miniaturized Multi Sensor Array for balloon-borne air measurements, Phase I.

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Introduction

Weber State University's High-Altitude Ballooning team, HARBOR, has seen an opportunity for cooperative research among the many individual balloon teams based in North America. The Great American Solar Eclipse brought these teams into the spotlight as dozens of ballooning groups worked together to image the eclipse. Leveraging this collection of balloon teams to create a large-scale data set could make some valuable discoveries and give us a better understanding of the atmospheric dynamics that take place in the stratosphere. Our team has decided to facilitate the creation of such a data set by designing an atmospheric data collection tool, the mini-Multi Sensor Array, that can be flown by teams all over the nation, and potentially the world.

Our goal is to create an inexpensive, lightweight, easy to assemble device which will measure gas concentrations, particulate matter, atmospheric turbulence, and meteorological parameters such as temperature, pressure, and humidity. We will also add features such as long distance telemetry, which will facilitate recovery of these payloads. Having a redundant, lightweight tracking device will increase the number of flight teams that are making a regular effort to fly our mini-MSA with their payload.

Device Fabrication

Building a prototype mini-MSA began from some of the projects that are already underway at Weber State University. Our AtmoSniffer is a fully fledged atmospheric sensor suite, whose motherboard and gas board formed the prototype of the mini-MSA. We also have an undergraduate learning board known as the Tricorder, which has different sensors that may find their way onto the final mini-MSA board. Sensors include volatile organic compounds, 6 gases, and particulate matter sensors.

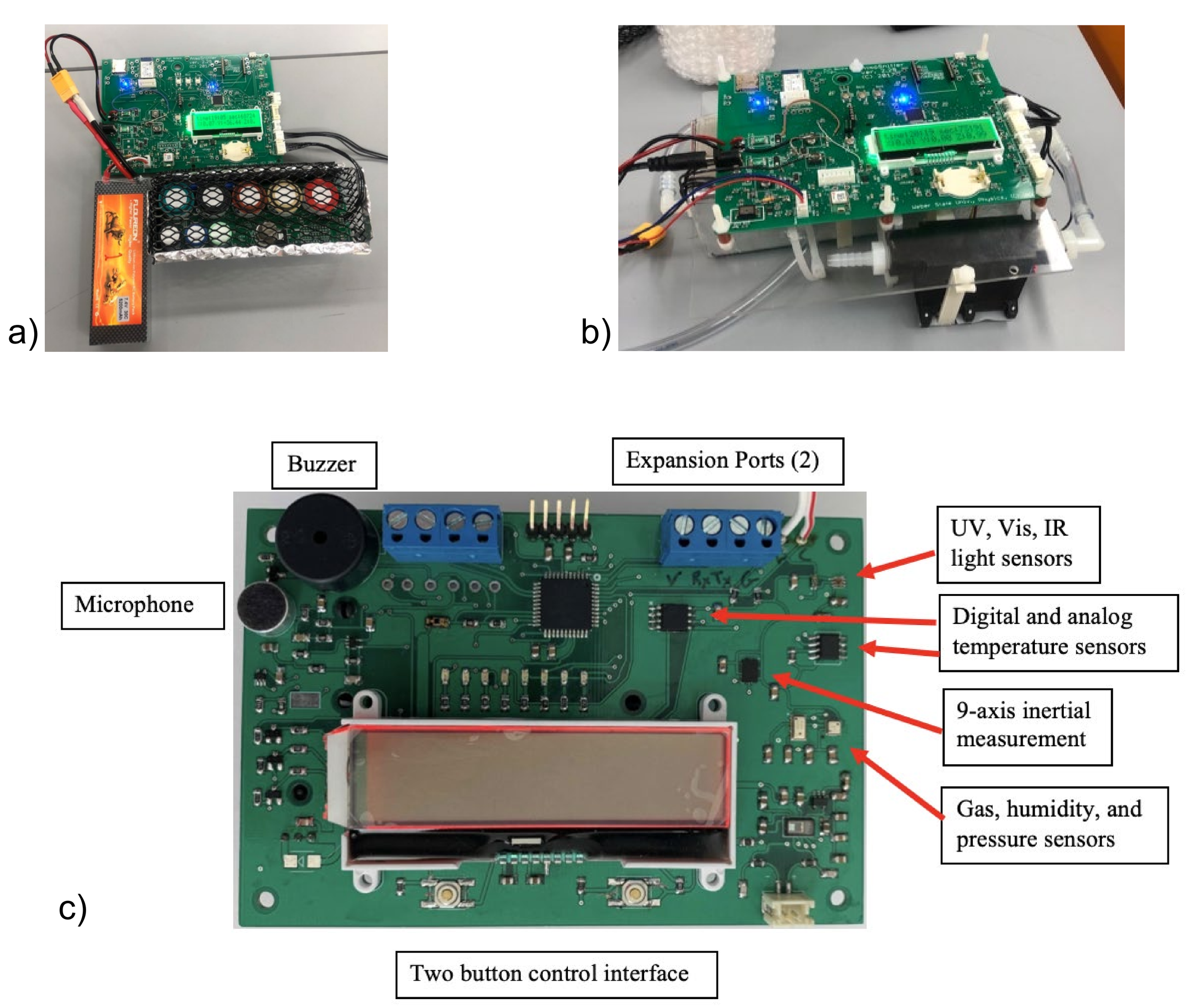

Figure 1: a) The mini-MSA prototype, with battery, and gas board inside of an electrically insulating Faraday cage. b) The AtmoSniffer along with its housing and pump. c) The "Tricorder" testbed which will be expanded with sensors and the radio from the first mini-MSA prototype.

Testing Methods

The mini-MSA differed from the parent product, the AtmoSniffer, by an important difference, the gas measurement board is no longer thermally or electronically insulated. This causes a two fold issue with gas measurement, first the sensors may function differently when they are cold, and they may not function at all while they are being blasted with high power RF radiation from our telemetry antennas. Our first goal was to electrically shield the device by means of a Faraday cage, which does not allow radiation to pass through, but allows atmospheric air to get to the sensors for measurement.

Verifying that the mini-MSA creates high quality data is of key importance to the project goals. To do this, the device was tested in a cold air, low pressure environment, alongside a device which has a calibrated gas measurement system, the AtmoSniffer. The gas sensors on both devices are identical, but the mini-MSA's sensors are exposed to the cold air, while the AtmoSniffer uses an insulating chamber to keep the air over the sensors warm. The experiment showed that some sensors behave wildly in these conditions, while other sensors have predictable changes that are easily accounted for.

These results will guide sensor selection for Phase II of the project.

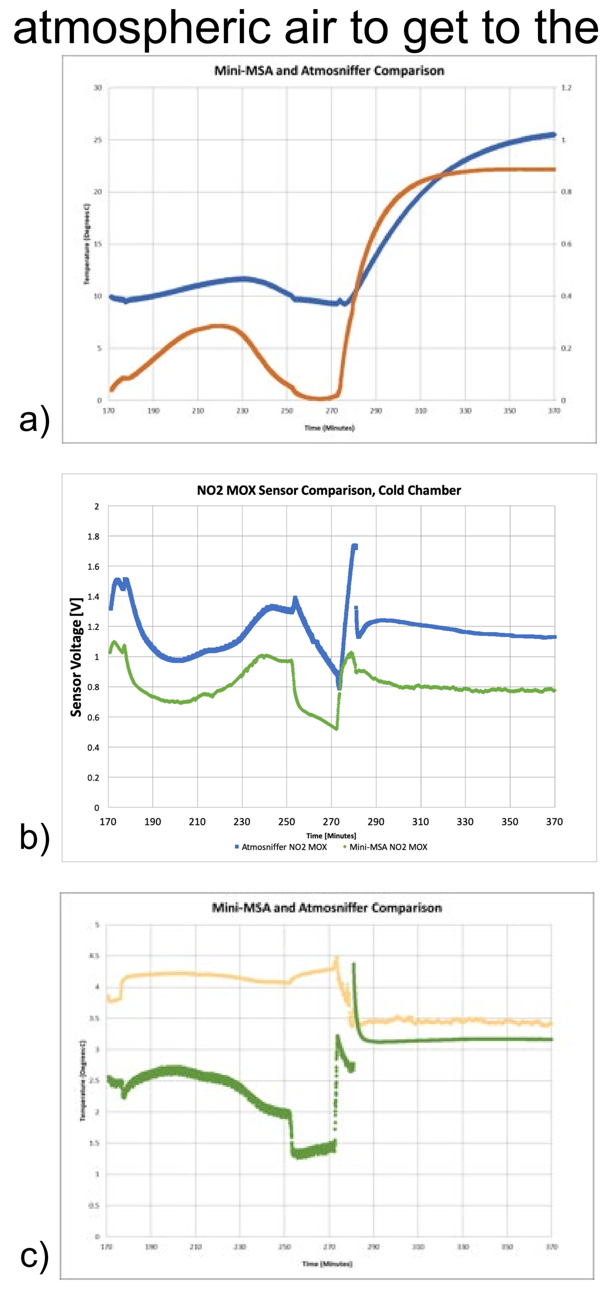

Figure 2: a) The temperature of the two devices in the experiment as a function of time. The orange line shows the temperature of the ambient gas that the mini-MSA is measuring, while the blue line shows the temperature of the conditioned gas the AtmoSniffer is measuring. b) A well behaved sensor whose NO2 measurements differ by a constant voltage shift. c) A poor quality sensor, whose data bears little resemblance to the AtmoSniffer measurements.

Sensor Evaluation

The main two types of sensors that populate the current iteration of the board are Metal Oxide Semi-Conducting (MOX), and Electro-Chemical (EC). Each has advantages and disadvantages. The MOX is slow to react to sharp changes in gas concentrations, and they constantly draw current from the battery to run a heater that is crucial to proper functionality. Alternatively, the EC sensor draws no current until there is a change in gas concentration, but the high input impedance of the device makes it sensitive to RF interference, as is common on a high-altitude balloon flight. The ideal board will contain a MOX and EC sensor for each gas of interest. This will create a complimentary data set in which the weaknesses of the two sensor types will be compensated for by the other.

Turbidity and Cameras

Balloon teams everywhere collect aerial photographs over the entire flight path. If they also fly a mini-MSA with a particulate matter counter, they should be able to correlate the in-flight images with the aerosol and humidity layers that they fly through. Since the mini-MSA has a GPS, we know the camera's location. Comparing that to the location of the ground target will allow the intervening air mass to be calculated. Teams can now add image resolution information to the overall dataset.

Currently the tens of thousands of photos taken by balloon teams every year are primarily used for "fun" PR images. The mini-MSA will allow teams to calibrate image resolution to estimate airborne pollution on a wider scale.

Clearly imaged ground locations that are observed during flight often include high contrast targets such as dark, asphalt roads next to white, concrete pads. These can be used as resolution targets. If the image has minimal motion-blur, it can be used with image processing software to quantify the pixel information into resolution/contrast values which can infer turbidity and atmospheric aerosol information. The mini-MSA's particle counter gives a direct comparison of aerosol information to the results gathered by this unique photographic method.

Conclusions & Future Work

As we move into the next stages of mini-MSA development, we will finalize the sensor suite that will populate the board and decide if the board will function with vacant sensor slots, so that teams can tailor the sensor suite to their budget and needs. This makes the board more affordable, but reduces the uniformity of the data set between teams. We need to fabricate the first full prototype of the board, which will eliminate the two-board design (gas and motherboard), and have an onboard solution for excessive noise in the electrochemical sensor data. The target board design will be approximately 3" by 5". Lastly, a flight frame will need to be designed in a 3D printer format, allowing for teams to print one in-house, or have it printed by a third-party. The current sensor suite measures temperature, pressure, humidity, and wind speed (by GPS). It also measures gas concentrations of NO_2, CO, CO_2, SO_2, O_3, and NH_3, as well as particle sizes and counts from 0.3 microns and 10 microns.

Acknowlegements

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