Developing a Novel Sensor Technology for Measuring Particulate Matter

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Background

- Particulate Matter (PM) pollution has become a concern due to its impact on human health and environmental degradation(1).
- Conventional technologies are limited in capturing variations in atmospheric PM concentrations at fine temporal and spatial scales.
- Recently, low-cost PM sensors (LCPMS) have been utilized to address the shortcomings of the conventional monitoring PM procedures(2).
- Ground-level measurements of PM fail to capture concentrations at different altitudes of the atmosphere.
- Unmanned Aircrafts (UA) serve as a viable tool to characterize the spatial distribution, of PM concentration at varying altitudes.

Objective

- **Goal:** monitor the horizontal and vertical atmospheric particle pollution using different types of LCPMS on UA in diverse environments in the state of Florida.
- **Motivation:** (1) understand how PM is dispersed in the atmosphere, (2) identify areas of concern such as areas prone to wildfires, hurricanes, etc., and (3) ultimately devise preventative control strategies for atmospheric PM.

PM Sensor Selection

Four sensors are used for data collection in this project (Fig. 1):
(a) Alphasense OPC-N3 (b) PurpleAir
(b) (c) Shinyei PMS1 (d) Adafruit PMSA003I.

- Sensors (Figs. 1a, b, d) operate based on optical properties and monitor PM_1, $PM_{2.5}$, and PM_{10}.
- Shinyei PMS1 (Fig 1c) is a nephlometer.
- The chosen sensors are known for their high accuracy, particularly in severe meteorological conditions; such as high temperature and/or humidity(2).

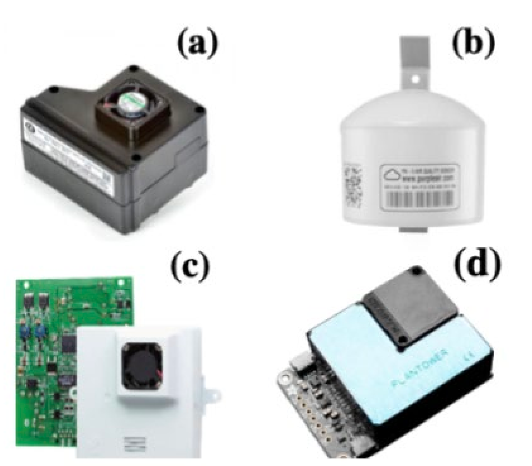

Fig. 1: LCPMS used in this study.

Selection of UA

- ERAU has a fleet of varied fixed-wing (FW) and multirotor (MR) UA, and various sensor suites.

1. **MR UA** is employed for its maneuverability, and ability to operate at low airspeeds, including hover.
2. **FW UA** can more efficiently cover extensive horizontal and vertical distances compared to its MR counterpart.


Fig. 2: UA used in this study.


Fig. 3: Alphasense OPC-N3 mounted on a UA.

- LCPMS were integrated into a UA hosted meteorological instrumentation suite (Figs. 2 and 3).
- LCPMS performance was evaluated in the field by comparing the sensor with an equivalent LCPMS, and a Vaisala AQT420 sensor, hoisted to the same level but outside of the rotor induced flow field of the UA.
- LCPMS were evaluated within their resident turbulent flow field against a LCPMS in a representative ambient atmospheric condition at the same altitude.
- Comparisons were made at different temperatures and relative humidity levels between the ground and 400 feet above ground level (AGL).

Sensor Integration

Current PM Sensor Weights

Device	Weight (lbs)
Shinyei PMS1	0.2913
AlphaSense	0.2576
2-Cell Lithium-Ion Battery Pack	0.2241
Arduino Uno/Prototype Shield v5/Xbee 3 Pro	1.0195

Xbee 3 Pro Airborne Telemetry Device:

- This device creates a mesh network that connects to other devices to send data over long range.
- This is a low-cost solution for sending and receiving live telemetry in real time.

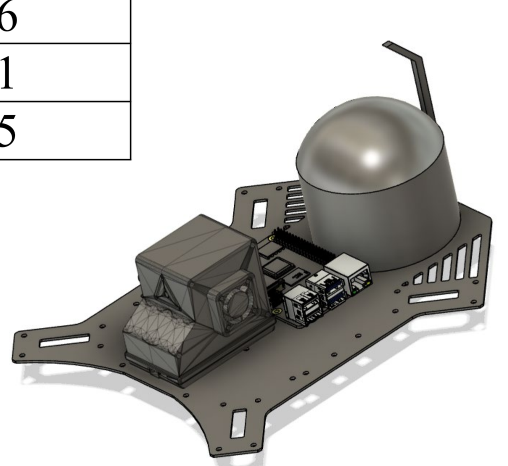
Fig. 4: UA Sensor layout.

PM Sensor Calibration

- Calibration is based on comparing PM concentrations form the LCPMS to a stationary PM monitor based on a Federal Equivalence Method, i.e., Teledyne T640x aerosol mass monitor (Fig. 5).
- Temperature and relative humidity levels were monitored simultaneously and these were used for correction of PM concentrations.


Fig. 5: LCPMS collocated with reference PM monitor.

- Three sets of each LCPMS were collocated (Fig. 6) to test repeatability(3).

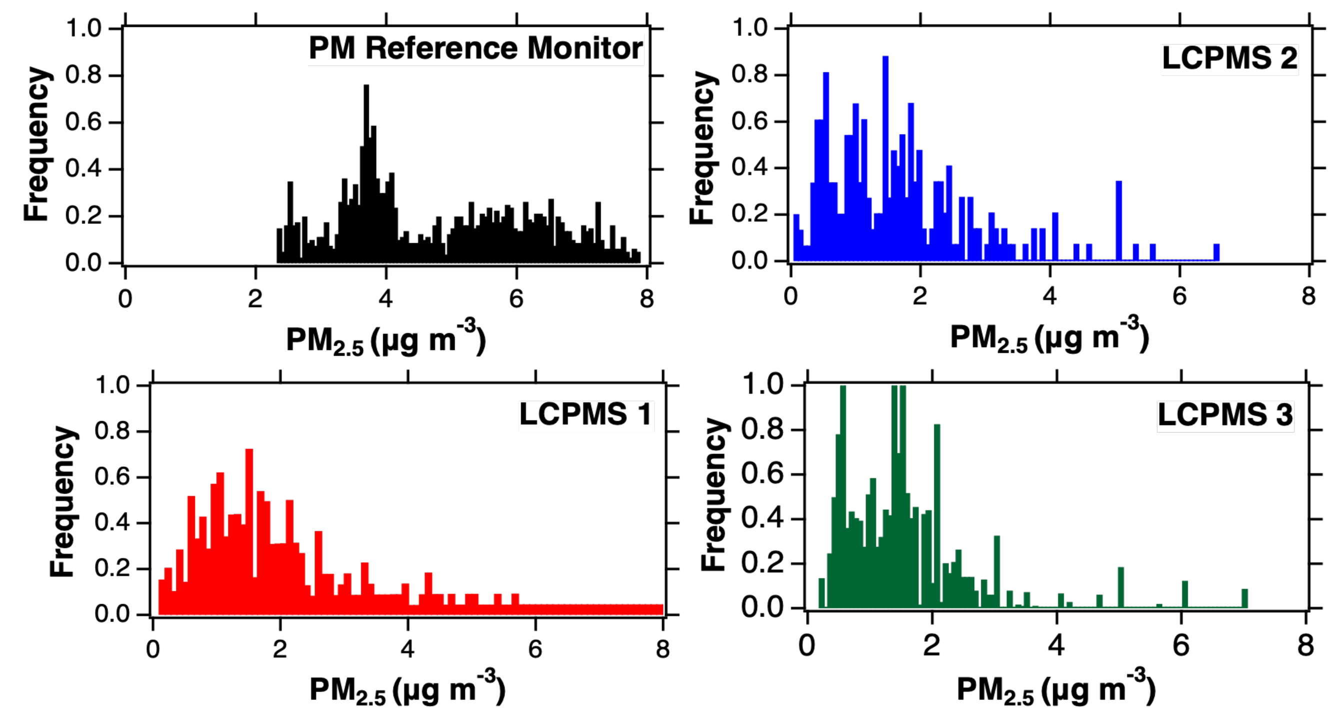

Fig. 6: Histograms of $PM_{2.5}$ concentrations using LCPMS and a PM reference monitor.

Sensor Validation on UA

- This validation step relies on comparing data from a Vaisala AQT420 sensor mounted on a tethered weather balloon carrying an OPC-N3 to an OPC-N3 mounted on a MR UA (Fig. 7).
- Flights took place at Coe Field up to 400 ft with PM measurements collected at 50 ft increments.

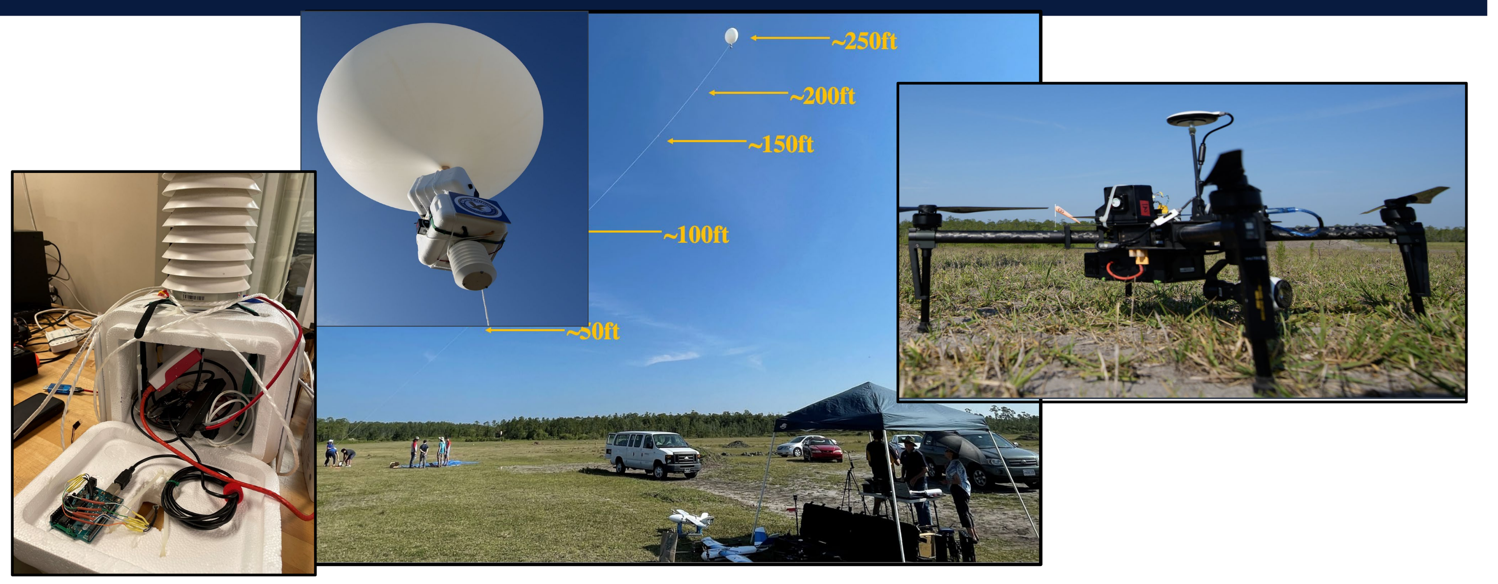

Fig. 7: LCPMC collocated with Vaisala AQT420 sensor mounted on a balloon.

Conclusions

- Calibration and validation of LCPMS experiments were conducted at the ground-level and on UA.
- Corrections of PM measurements will be established taking into consideration meteorological variations.
- LCPMS will be further validated in three modes: (a) stationary, (b) manned vehicles, and (c) unmanned vehicles.

References and Acknowledgments

1. National Ambient Air Quality Standards (NAAQS) for PM, EPA.gov, 2021.
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3. Jagatha, Janani V.: Sensors, 2021.

Recommendations

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