Developing a Novel Sensor Technology for Measuring Particulate Matter

Andres Munevar[1], Leah Smith[2], Erik Liebergall[2], Kaleb Nails[2], Robert Moore[3], Marc Compere[2], Kevin Adkins[3], Marwa El-Sayed[1]

[1] Department of Civil Engineering, Embry-Riddle Aeronautical University

[2] Department of Mechanical Engineering, Embry-Riddle Aeronautical University

[3] Department of Aeronautical Science, Embry-Riddle Aeronautical University

Marwa El-Sayed | elsayedm@erau.edu | 919 – 600 – 1968

Background

- Particulate Matter (PM) pollution is a concern due to its impact on human health and the environment(1), hence, the National Ambient Air Quality Standards (NAAQS) as shown in Table 1.
- PM is defined as liquid or solid particles suspended/dispersed in the atmosphere(2).
- EPA Federal Reference and Equivalent methods are limited in capturing PM spatial and temporal variations.
- Low-cost PM sensors (LCPMS) are utilized to address these shortcomings(3) while considering the P3 model of sustainability (Fig. 1).

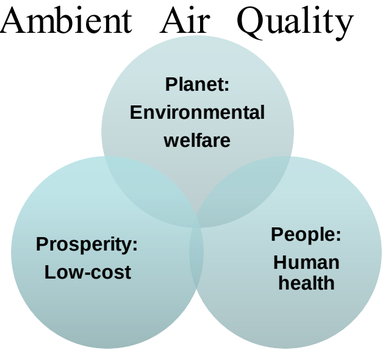

Fig. 1. The P3 sustainability model and its association with this study.

Objective

- **Goal:** Evaluate the performance of different types of LCPMS in diverse environments at various modes of operation.
- **Motivation:** Characterize PM levels in the atmosphere to ultimately devise preventative control strategies.

Table 1: U.S. EPA PM National Ambient Air Quality Standards.(1)

Particle Pollution (PM)	$PM_{2.5}$	primary	1 year	12.0 µg/m^3	annual mean, averaged over 3 years
		secondary	1 year	15.0 µg/m^3	annual mean, averaged over 3 years
		primary and secondary	24 hours	35 µg/m^3	98th percentile, averaged over 3 years
	PM_{10}	primary and secondary	24 hours	150 µg/m^3	Not to be exceeded more than once per year on average over 3 years

Methodology

Three modes of operation are used, namely:

1) ***Stationary***: sensors housed in an outdoor temperature-controlled environmental enclosure on ERAU campus (EcoTech, Fig. 2a).
2) ***Manned mobile***: sensors mounted on an air-conditioned trailer and a Ford F-250 Pick-Up Truck on UCF and ERAU campuses as well as I-4 highway (Fig. 2b).
3) ***Unmanned mobile***: Sensors mounted on a Motor Unmanned aircraft (UA) and fly up to 400 ft AGL on ERAU campus (Fig. 2c).

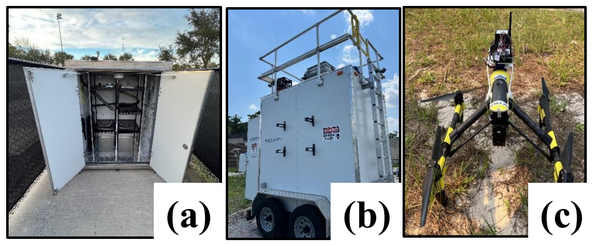

Fig. 2. (a) Environmental enclosure, (b) Mobile trailer, and (c) unmanned aircraft.

PM Sensor Selection

Three sensors are used for data collection (Fig. 3):

(a) Alphasense OPC-N3
(b) PurpleAir
(c) Adafruit PMDS003

Fig. 3: LCPMS used in the study.

- Sensors operate based on optical properties and monitor various sizes of PM.
- Sensors were chosen due to their high accuracy, particularly in several meteorological conditions; i.e., high temperature and/or humidity(4).

Sensor Integration

(1) Stationary
- 3 PurpleAir
- 3 Alphasense OPC-N3
- 1 Vaisala

(2) Manned mobile
- 3 PurpleAir
- 2 Alphasense OPC-N3
- 1 Vaisala

(3) Unmanned mobile
- 1 Alphasense OPC-N3
- PMS5300
- SPS 30

Stationary and manned mobile (Fig. 4).

- All 7 sensors are integrated using Arduino (C) which speaks directly to the Raspberry Pi or uploads data to the web automatically.
- When connected to Wi-Fi, the Pi can send data to a google drive folder that can automatically upload data online for real-time data analysis.

Fig. 4: Sensor suite.

The Unmanned mobile data is stored on the Pi while in flight (Fig. 5).

- Sensors are integrated using Python where they are wired directly into the Pi.
- Due to wireless limitations, the Pi is later connected to Wi-Fi and data is uploaded for users to access.

Fig 5: UA in flight on ERAU campus.

Sensor Performance

- The performance of LCPMS was evaluated by comparing LCPMS data to the following reference PM monitors (Fig. 6):
  1. Vaisala AQT420 sensor
  2. DustTrak DRX
- Statistical analyses were conducted by testing the following:
  - The coefficient of correlation (R^2)
  - Normalized mean error (NME)

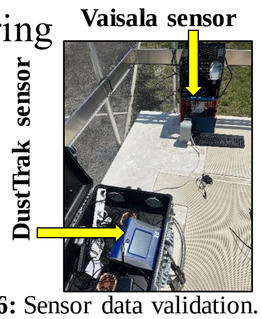

Fig. 6: Sensor data validation.

Conclusions and Future Work

- LCPMS on manned and unmanned vehicles may serve as viable tools to characterize the spatial distribution of PM concentrations in 2D and 3D, especially in locations prone to wildfires, hurricanes, etc.
- In the future: we will calibrate the sensors against meteorological conditions including temperature and relative humidity and test the sensors in urban, suburban, and rural areas.

References

1. EPA, National Ambient Air Quality Standards (NAAQS) for PM, EPA.gov, **2021**.
2. Seinfeld, J. H., and Pandis, S. N.: Atmospheric chemistry and physics: from air pollution to climate change, **2016**.
3. Johnson, K. K., et al.: *Aerosol and air quality research*, 18(3), 565–578, **2018**.
4. Sousan, S., et al.: *Aerosol Sci. Technol.*, 50, pp. 1352-1365, **2016**.

Acknowledgements

1. University of Central Florida (UCF) professor Dr. Haofei Yu, for providing the EPA PM monitor.
2. Environmental Protection Agency (EPA) grant number .
3. Embry-Riddle Office of Undergraduate Research OUR IGNITE funding.
4. Embry- Riddle Student Government Association funding.