Enhancing Nighttime Measurement Precision in an Aerosol Optical Depth Monitor Using LED Technology

Problem Statement

- **Criteria**:
  - To have the sensor work all day
  - To not be reliant on being lit by the sunlight
  - To cost under $20 for the completion of one model
  - R^2 is greater than .95 to ensure precision of trials
- **Constraint**:
  - PM2.5 and PM10 will not be identified, meaning that all particulate matter will be classified as "PM pollutants" which will limit the accuracy of the particle identification
- **Problem Statement**:
  - The purpose of this project is to redesign a sunlight-based AOD monitor into an LED-based system for enhanced nighttime measurement capability.

Literature Review

- **Air pollution** is closely related to economic growth, population and energy consumption (Jafari et al. 1)
- Contaminated air can produce a lot of waste, and air pollution is a health problem that affects many people worldwide (Rentschler et al. 1)
  - There is an estimate of around **4.2 million** people that die from contaminated air (Rentschler et al. 1)
- Long term interactions with the toxic particles can negatively affect the **cardiovascular** and the **respiratory system**, and can also affect mental health and behavioural and learning issues (Brook et al. 6)
- Air quality sensors can increase people's **awareness** of the environment around them (Singh et al. 1)
- The two popular air quality sensors are ground sensors and satellite sensors (Dubovik et al. 4)
- **Ground sensors** provide more **accuracy** than satellite sensors (Bloom et al. 1)
  - Although satellite observations are good for aerosol dynamics, there can be many factors that affect it which can create **data gaps** (Liang et al. 1)

Fig. 1 shows a popular option for ground sensors (Unmanned Tech)

- Ground air quality sensors measure in **Aerosol Optical Depth (AOD)** (Yang et al. 1)
- High-quality, long-term **AOD data** is **important** for understanding air quality, climate change and public health (Liang et al. 1)
- Some ground models also use methods such as electro-chemical, catalytic, solid-state, non-dispersive infrared, and photoionization, but have problems such as lower accuracies, a limitation for 3-dimensional data acquisition, and scalability from known locations to unknown locations (Singh et al. 2)
- A current ground model that can **accurately measure** AOD data **during the daytime** is the aerosol mass and optical depth **(AMOD) sampler** (Wendt et al. 5431)
- There are many benefits to using LEDs, such as being small in size, having low power requirements, having high **efficiency**, high **reliability**, self heating, high switching frequency, and shock resistance (Chang et al. 1)

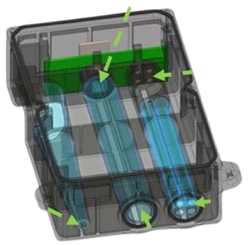

Fig. 2 shows the AMOD sensor with the different apertures that let in sunlight (Wendt et al. 5433)

- LEDs are the **least expensive** option when building the sensor (AMOD sampler), however, it is unknown if the sensors will respond well to LEDs with narrow wavelengths (Wendt et al. 5433)

Experimental Design

- **Device Design:**
  - Original Model: Aerosol Mass and Optical Depth (AMOD) sampler that used solar-powered energy
  - Modification: Added a mini LED light inside the central aperture to allow it to be used during the day and the night since previous model was solar powered and was only usable during the day
- **Experimental Method:**
  - **Setup:**
    - Fan was placed in front of sensor to ensure constant flow of particles-more particles would mean a clearer change in AOD
    - LED light was on top of model, which was on top of the LUX sensor to ensure light passed through-clear passage of light to LUX sensor meant limited possibilities of existential factors
    - Air pump was placed opposite of the fan to maintain constant flow of air-pulled air out of sensor so that it would not get stuck
  - LUX values were recorded every 5 minutes, for a total of 50 minutes, trials were repeated three times then averaged
- **Calibration Process:**
  - AOD calculation was done with a modified Beer-Lambert law
- **Project Collaboration:**
  - Model provided by the mentor and University of New Haven
  - Mentor recommended design possibilities, mentee carried out experimentation

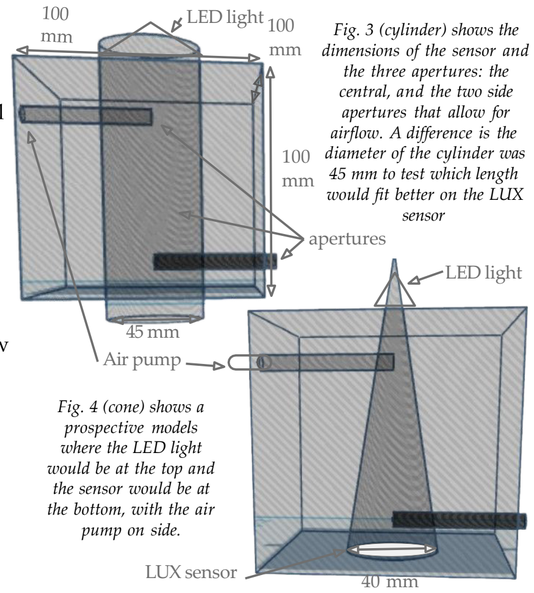

Fig. 3 (cylinder) shows the dimensions of the sensor and the three apertures: the central, and the two side apertures that allow for airflow. A difference is the diameter of the cylinder was 45 mm to test which length would fit better on the LUX sensor

Fig. 4 (cone) shows a prospective models where the LED light would be at the top and the sensor would be at the bottom, with the air pump on side.

Results

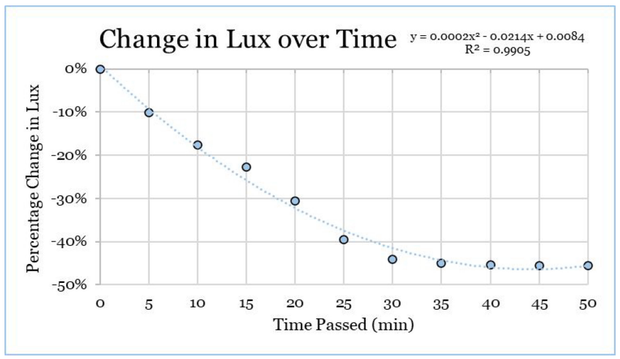

Fig. 5 shows the percentage change in light intensity over time. The curve shows a steep initial decline in percentage light intensity over the first 15 minutes, which gradually stabilizes as the aperture filled up. The curve gradually turns into a plateau. LUX values varied slightly due to ambient factors, but the percentage change in light absorption was consistent across trials, validating repeatability.

- The percentage change was found for each trial, although initial LUX values varied the difference between each increment was used to calculate the percentage
- The formula used to calculate change was **(measured value-initial value)/initial value**

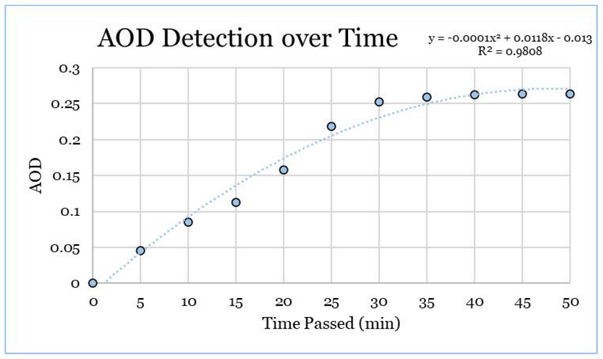

Fig. 6 shows the progression of AOD (Aerosol Optical Depth) over a 50-minute period. Data points indicate observed values at specific time intervals, while the trendline illustrates the modeled changes, capturing the gradual increase and eventual plateau of AOD levels. The data points and trendline have many similarities to Fig. 5 but represent different units: LUX and AOD.

- The data points and trendline look similar between the two graphs but the AOD graph was created using the modified Beer-Lambert law: **-log(final value/initial value)** with the values being the LUX values at zero and every increment of 5 minutes

Discussion

- Determined the effectiveness of LED lights in powering a AMOD sensor to enhance night time precision
- Fig. 5 has an r^2 of **0.995** for a quadratic (^2) trendline, supporting the idea that as time went on, there became less change in the LUX values
- One of the reasons that it took so long for the particles to occupy the entire cylinder is because the cylinder had a large empty space (the main aperture) (Burada et al. 45)
- Fig. 5 has an r^2 of **0.9808** for a quadratic (^2) trendline, showing a likable probability of accurately finding AOD
  - AOD detection **increases initially** as aerosol concentration rises, but it **plateaus** when the system reaches its sensitivity limit or when light is fully reduced reducing additional measurable changes (Li et al. 1)
  - The quadratic curve may represent how the detection increased as AOD **increased**, but then slowed down because it had reached its **maximum threshold**
- However, the hollow cone design was not tested because of its **inability to produce sufficient data**
  - The design was not compatible with the diameter of the LUX sensor
- In the future it would be beneficial to **reduce the main aperture** and a **smaller LUX sensor** to minimize other factors by testing different hollow shapes
- The success of this design demonstrates its potential benefits to environmental scientists in tracking patterns in air quality due to its cost-effectiveness and compact design
- The introduction of LED technology could significantly enhance the precision of AOD measurements during **low-light conditions**, reducing errors especially on days where solar-powered systems do not work
  - Would enable more reliable monitoring of aerosol concentrations, which would advance society's knowledge about the air quality of the environment around them
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