Tomographic Reconstruction of Spatial Aerosol Distribution using Multispectral Light Extinction Measurement

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Background

- Mapping the aerosol concentrations in a facility (i.e., a hazardous waste site) for occupational exposure assessment purpose is important but challenging.

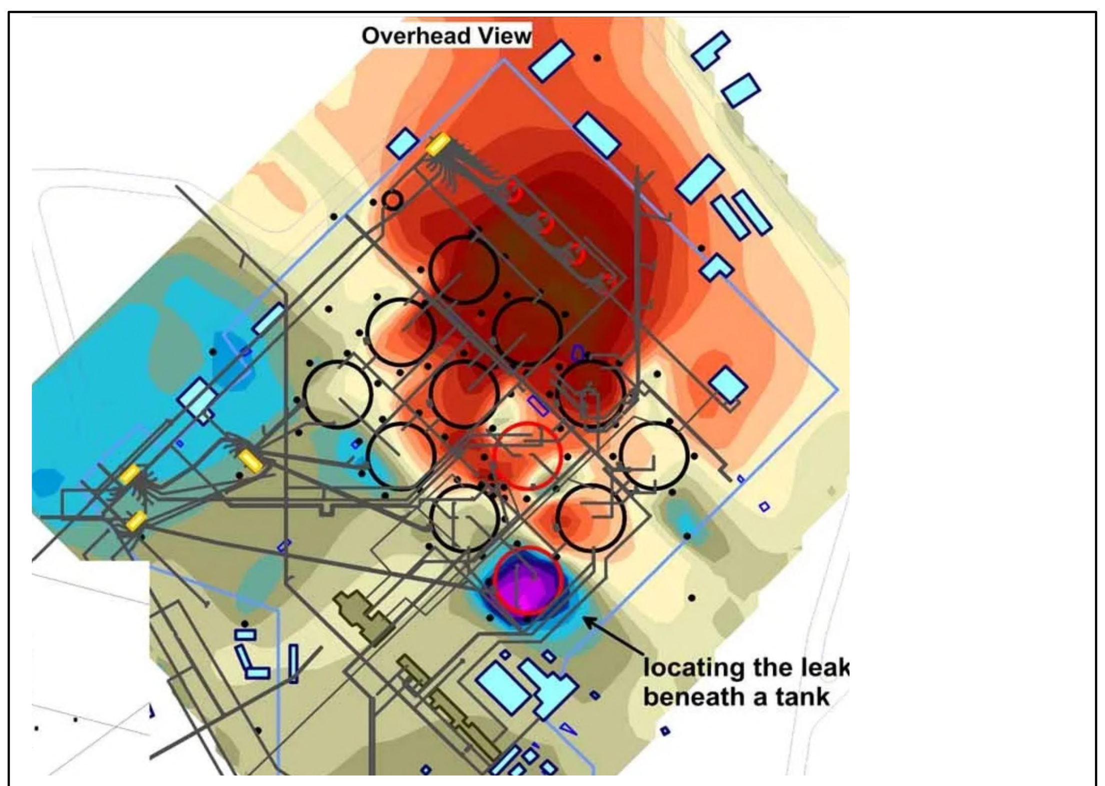

Figure 1. Conceptual image of the aerosol spatial mapping for an industrial park (https://www.hgiworld.com/services/environmental/plume-mapping)

- Inspired by medical CT scans, the idea of using optical sensing system combined with computed tomography technique (OS-CT) for spatial mapping purpose was initially proposed in the 1990s [1].

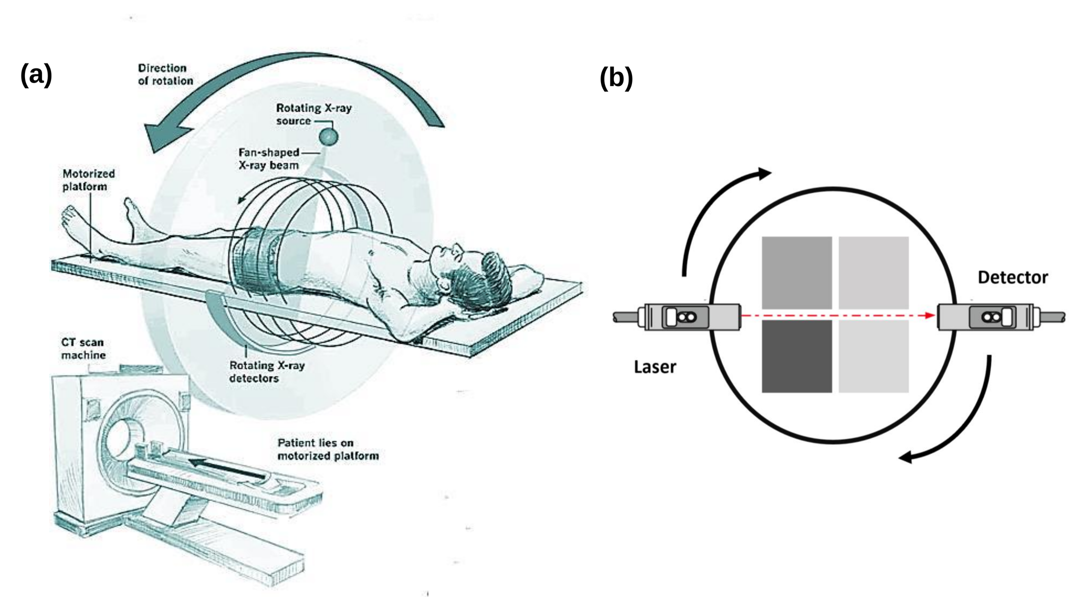

Figure 2. (a) Anatomy of medical CT scan (https://hkhjoshua.wordpress.com/2014/10/17/new-post/); **(b)** Overhead view of a conceptual OS-CT system

- A two-step approach for aerosol spatial mapping following the OS-CT idea was proposed by the same team, and its feasibility has been tested in a series of computer simulations [2,3].

STEP1: To build an optical sensing (OS) system, in which aerosol information of one spatial location can be extracted from multispectral light extinction data of this location.

STEP2: To build a computed tomography (CT) system, in which multispectral light extinction data for every spatial location in a plane can be extracted from path-integrated light extinction data.

Objectives

- To design a chamber study to validate the feasibility of using an OS-CT system to simultaneously determine the aerosol size distribution and concentration at different locations in a two-dimensional plane.
- **Aim 1:** To assess the quality of reconstruction of the size distribution and concentration of moderately polydisperse aerosols (1.2<GSD<2.5) with CMD between 300 nm and 2500 nm at one spatial location from light extinction measurements made at multiple wavelengths in the range of 340 nm – 940 nm.
- **Aim 2:** To assess the quality of reconstruction of the size distribution and concentration of moderately polydisperse aerosols (1.2<GSD<2.5) with CMD between 300 nm and 2500 nm at every location (four locations in this pilot study) in a plane from light extinction measurements made at multiple wavelengths in the range of 340 nm – 940 nm via computed tomography reconstruction.

Methods

- **STEP 1: Extraction of aerosol-size distributions from multispectral light extinction data**

  - **Fredholm integral equation of the first kind**:

    The relationship between light extinction measurements and the unknown aerosol size distribution is described by the following equation:

$$\tau_i = -\ln\left(\frac{I_t}{I_0}\right)_i = \frac{\pi}{4} C_n L \int_0^{\infty} Q(\pi p/\lambda_i, m) f(p) p^2 dp$$

where, τ_i denotes the light extinction by the aerosol at wavelength λ_i, $i=1,2,\ldots N$, N denotes the number of different wavelengths; I_0 and I_t are the initial and transmitted light intensity at wavelength λ_i; L is the pathlength of the light beam; $Q(\pi p/\lambda_i, m)$ is the extinction coefficient of an aerosol with diameter p at wavelength λ_i calculated using Mie extinction theory; m denotes the complex refractive index of the aerosol at wavelength λ_i; $f(p)$ is the unknown aerosol size distribution function and C_n is the unknown number concentration of the aerosol, the goal is to determine these unknowns from light extinction measurements made at multiple wavelengths.

  - **Experimental design**

    A lab-scaled optical sensing (OS) system which comprises 7 pairs of laser sources and laser detectors was designed and built in the lab (as shown in Figure 3). We will be testing the how well this system can extract aerosol information for various types of testing aerosols in our controlled lab environment.

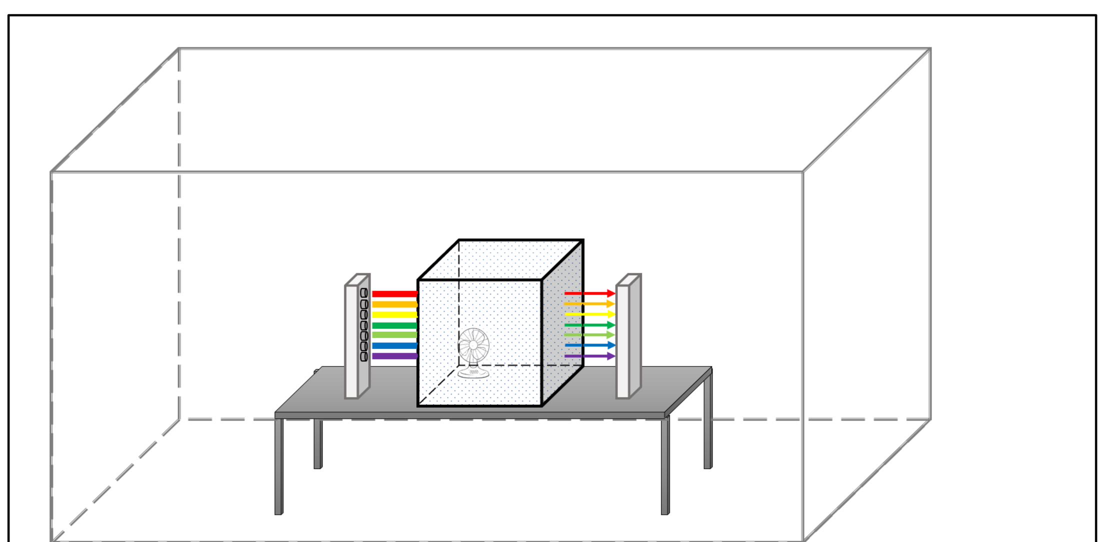

Figure 3. The light extinction system for measuring light extinction at multiple wavelengths to obtain the aerosol size distribution at one location (Aim 1)

- **STEP 2: Extraction of spatial aerosol distributions from multispectral light extinction measurements with computed tomography**

  - **Experimental design**

    Design and build a computed tomography (CT) system. A circular track with automated dollies, on which the laser sources and detectors are installed, will allow us to complete a 360-degree scan (as shown in Figure 4) to acquire enough information about the aerosol information of multiple locations.

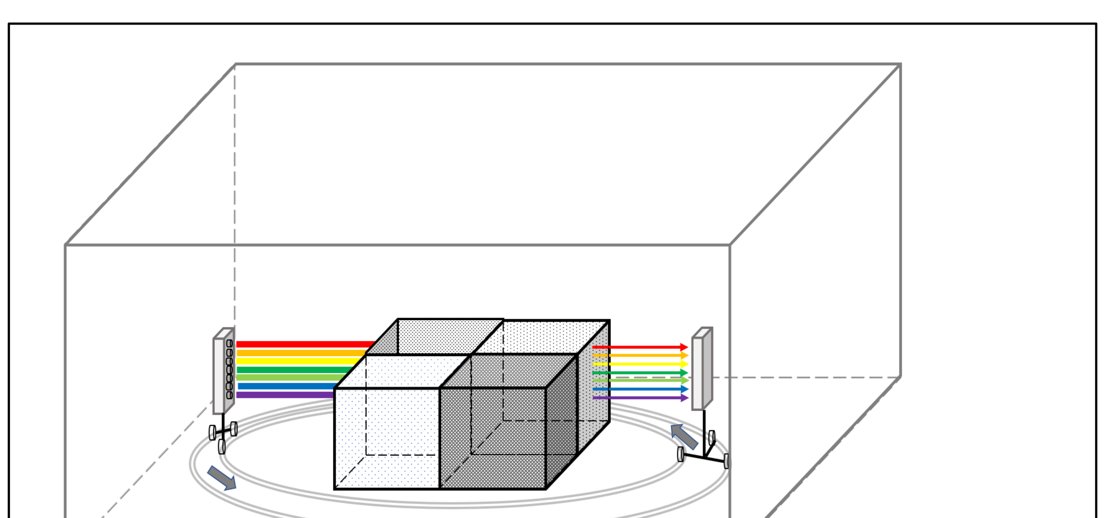

Figure 4. The schematic of the CT system for mapping the aerosol spatial profile at 4 different locations (Aim 2)

  - **Tomographic inversion algorithm**

    - Algebraic reconstruction technique (ART);
    - Simultaneous algebraic reconstruction technique (SART);
    - Maximum likelihood expectation maximization (MLEM);

Current Progress

- **Design and construction of a full-size exposure chamber**

- **Volume:** 907.5 ft³ (25.7 m³)
- **Dimension:** 11'x11'x7.5' (3.4x3.4 x2.3 m)
- **Adjustable ventilation rate**: 0~20 air change per hour (ACH)
- **Adjustable room temperature**: 60~100 °F(15~38°C)
- **Adjustable room humidity:** 30%~50%

Figure 5. The exposure chamber at Johns Hopkins University

- **Design and construction of an optical sensing system**

(a)

- **Laser sources:** 7 semiconductor lasers, each with a unique wavelength from HangZhou NaKu Technology Co., Ltd (China)
- **Laser detectors:** 7 PowerMax-USB PM10 real-time light intensity meters from Coherent Inc.(USA)

(b) (c)

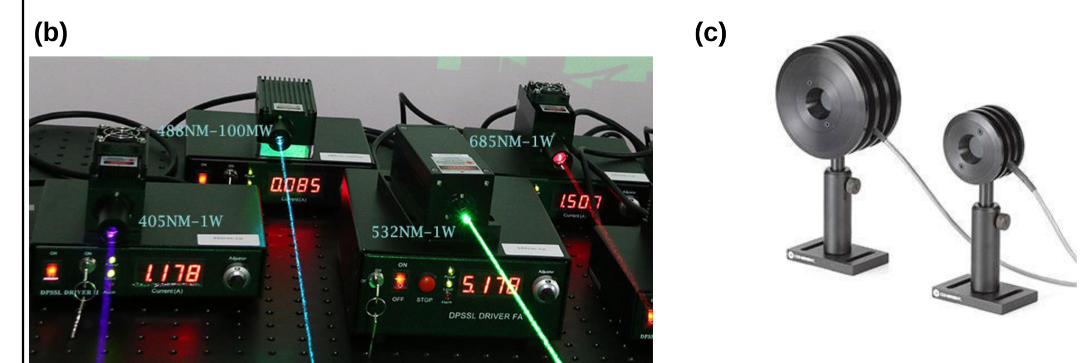

Figure 6. (a) Photo of our optical sensing system; **(b)** Photo of our laser sources; **(c)** Laser detectors; (https://www.coherent.com/measurement-control/measurement/high-peak-power-thermopile-sensors-rohs)

- **Testing the optical sensing system using different aerosols**

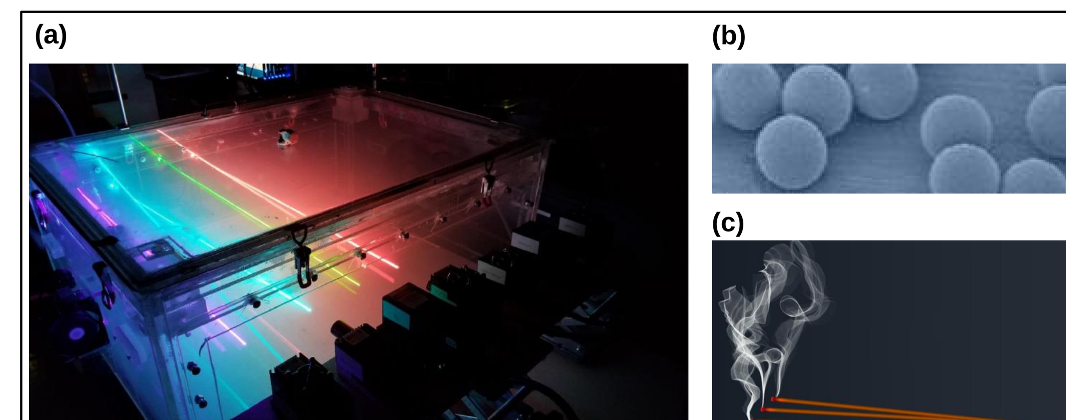

Figure 7. (a) Photo of lasers passing through test aerosols in the chamber; **(b)** Polystyrene Latex (PSL) Spheres; **(c)** Aerosols from incense burning process;

  - Incense stick burning experiment

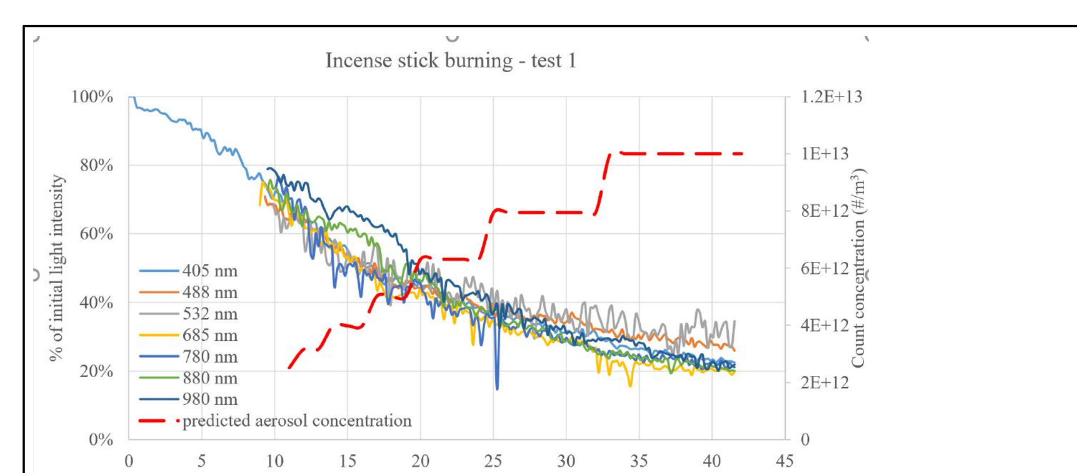

Figure 8. Predicted aerosol number concentration in the chamber from real-time multispectral light extinction measurements

Next Steps

- Complete all the tests for optical sensing system;
- Build and test the computed tomography system;
- Optimize CT algorithm;
- Conduct field studies;

References & Acknowledgements

[1] Todd, L., & Leith, D (1990). Remote Sensing and Computed Tomography in Industrial Hygiene. Am Ind Hyg Assoc J, 51(4), 224-233.

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[4] Ma, L., & Hanson, R. K. (2005). Measurement of aerosol size distribution functions by wavelength-multiplexed laser extinction. Applied Physics B, 81(4), 567-576.

This work was funded by the Johns Hopkins Education and Research Center (2 T42OH008428-14-00) Pilot Project Research Training Grant Program. Dr. Yuan Shao is a NIEHS T32 postdoctoral fellow.

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