Investigating Efficient Flight Routes with Continuous and Discrete Sensing for UAV-based Greenhouse Gas Monitoring at Environmental Infrastructures

Horim Kim*[1,2], Keun Taek Kim[1], Hyeri Jo[1], Minyong Yang[1], Young Su Lee[1], Sangjae Jeong[3], Jae Young Kim[1]

[1] Department of Civil and Environmental Engineering, Seoul National University, Seoul, Republic of Korea
[2] Institute of Construction and Environmental Engineering, Seoul National University, Seoul, Republic of Korea
[3] Department of Civil and Environmental Engineering, Hanbat National University, Daejeon, Republic of Korea

*E-mail : harriskim007@snu.ac.kr

Introduction

- Greenhouse gas emissions from environmental infrastructures (e.g., landfills, wastewater treatment plants, incinerator plants) constitute significant sources of anthropogenic air pollution.

- Conventional monitoring methods frequently struggle to capture the spatial variability and real-time fluctuations in emissions. The application of unmanned aerial vehicles (UAVs) in assessing greenhouse gas emissions has been highlighted owing to its capacity for rapid, wide-scale data collection.

- Efficient flight routes and sampling methodologies are crucial for UAV-enabled greenhouse gas monitoring, enhancing data precision and effectiveness. However, technical limitations persist, concerning the restricted flight duration and limited payloads of the measurement instruments.

Objective

The current study explores suitable flight pathways and sensing methodologies for UAVs measuring greenhouse gas emissions in two environmental infrastructures: a wastewater treatment facility and an incinerator plant.

Materials and Methods

UAV and Sensor system

- UAV: DJI Matrice 300 RTK
  - Maximum loadable weight : Approx. 2.7 kg
- Sensor modules developed *Soarability Technology LLC.* (Shenzhen, China)
  ① Electro-chemical sensor modules for CO, NO_2, H_2S, O_3, VOCs, and particulate matters
  ② Ultrasonic anemometer (modified *LI-COR* LI-550)
  ③ TDLAS (Tunable Diode Laser Absorption Spectroscopy)-based **CH_4** sensor
  ④ NDIR (Non-Dispersive Infrared)-based **CO_2** sensor

Fig 1. Four sensor modules installed on DJI Matrice 300

Site specifications

- Gajwa wastewater treatment plant (Incheon, Republic of Korea)
- Incinerator plant at resource recovery facility (Suwon, Republic of Korea)

Fig 2. Aerial views of investigated environmental infrastructures: (a) wastewater treatment plant and its process sector; and (b): incinerator plant. Images are generated by Google Earth Pro.

Types of flight routes

- **Boundary and Horizontal flight**

[Boundary flight]
X + 2Δ_v m
X + Δ_v m
X m : Initial altitude above ground-level
Δ_v : Vertical Interval

[Horizontal flight]
X m : Altitude above ground-level
Δ_h : Horizontal Interval

- **Hovering* and Non-hovering flight**

[Hovering flight]
T sec. : Hovering time
Δ_d : Hovering distance
* Hovering flight refers to the flight movement that maintain a stationary position and altitude in the air.

[Non-hovering flight]

Flight specifications

- Maximum flight time with sensor modules: approx. 25 minutes
- Flight speed: 5 m/s
- Hovering time: 10 seconds
- All flight routes were pre-determined and operated the UAV on autopilot.

Results of UAV-based Monitoring

* All figures depict concentration maps, which are linearly interpolated from data points scattered along the flight routes.

Case 1: Hotspot detection in the wastewater treatment plant

- CH_4 concentration hotspots were detected in the aerator process sectors (A2O: Anaerobic-Anoxic-Aerobic method, MLE: Modified Ludzack-Ettinger method).

Case 2: Plume detection at the incinerator plant at resource recovery facility

- Incinerator stack height : 109 m
- Theoretical altitudes from the Gaussian plume dispersion model were calculated and applied to flight routes for autopilot.

Fig 3. Boundary flight routes for the incinerator plant

Route A] Boundary, Non-hovering flight   Route B] Boundary, Hovering flight

- Plumes were detected during both hovering and non-hovering boundary flights at side W. Northwesterly winds were dominant on the investigated day.
- The non-hovering flight exhibited a short duration within the plume, leading to an underestimation of the CO_2 concentration. A significant contrast is observed in the maximum CO_2 concentrations between Route A and B.

Route C] Horizontal, Hovering flight at different altitude (135 m and 145 m from the ground-level)

- Horizontal flight above the incinerator stack detected the plume direction and the dispersion scheme.

Summary and Future Directions

- **The UAV-based monitoring system effectively detected pollution zones at the environmental infrastructures.**

- **Hovering flight could lead to significant discrepancies in the measurements.**

- **The UAV observation technique should be further developed to accurately quantify greenhouse gas emissions by efficiently collecting both concentration and meteorological profiles.**

Acknowledgement