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Performance Assessment of Methane and Carbon Dioxide Sensors for Drone-Based Environmental Gas Monitoring

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Summary:

This study evaluates the performance of methane (CH_4) and carbon dioxide (CO_2) sensors mounted on an unmanned aerial vehicle (UAV) for gas detection in open-field environments. Sensors were tested simultaneously during UAV flights over artificial gas sources, with wind data collected from two anemometers to understand plume dynamics. Field-deployed CH_4 sensors provided validation for the UAV-based measurements. The results demonstrate the sensors' effectiveness in gas detection.

Keywords: UAV-based gas sensing; Sensor comparison; Methane and carbon dioxide detection

1. Introduction

Detecting and monitoring methane (CH_4) and carbon dioxide (CO_2) is a key task that can be effectively accomplished using remotely operated platforms equipped with specialized sensors. Various sensor systems are currently available for deployment in mobile platforms such as unmanned aerial vehicles (UAVs) [1,2]. These payload systems typically are in conjunction with environmental sensors, enabling more accurate detection of CH_4 and/or CO_2 leaks and enhancing the monitoring of industrial gas sources [3]. To facilitate a transition from using individual sensors to an integrated network of mobile and stationary sensors, we initiated an experiment aimed at improving monitoring capabilities. This approach explores sensor limitations and enhances the understanding of their comparability across diverse deployment scenarios, including UAV-based applications.

2. Materials and Methods

2.1 UAV Platform

The DJI M300 RTK (Da-Jiang Innovations Science and Technology Co., Ltd, Hangzhou, China)(Fig1) is a commercially available quadcopter suitable for operating in harsh weather conditions. It offers a maximum flight time of 55 min and can carry up to 27 kg. In our case, the UAV was equipped with two different gas sensor setups:

1)Sniffer4D sensor (with a measurements range of 300-50, 000 ppm) mounted on the top of the platform: a Cubic SJH-5 (with a measurement range of 0–5000ppm CH_4) and SCD30 (with a measurement range of 400–10,000 ppm CO_2).

2)Cubic SJH-5 and SCD30 for CH_4 and CO_2 and MH-Z19B sensors for CO_2 mounted on the lower part of UVA.

The MH-219B sensor was operated on passive diffusion, while the Sniffer4D utilized its own integrated active gas inlet. In contrast, the SJH-5 and SCD30 sensors were connected to 2 m sampling tube for active sampling.

2.2. Experimental Setup

The experiments were conducted outdoors at BAM TTS (Technical Safety Test Site, Horstwalde Brandenburg, Germany). The experimental setup used 100% CH_4 and CO_2 gas cylinders as artificial sources connected to a tube and a fan to disperse the gas plume in the experimental area (Fig. 2).

Figure 1. DJI Matrice M300 RTK with i) Sniffer4D ii) SJH-5 and SCD30 sensors.

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The fan's position was adjusted vertically between 0° and 80° to create different plumes. Two ultrasonic anemometers (uSonic-3, Metek GmbH) were placed approx. 5 m apart and mounted at a height of 3 m to monitor wind conditions. A network of 10 stationary CH_4 sensors (Dräger PIR 7000) was mounted on stands at 1 and 2 m height, respectively, providing high-resolution CH_4 data. In total, three experimental trials were conducted to survey the area near the fan and stationary sensor network. Two flights used sensor setup #1, while the other used sensor setup #2 for evaluating the aerial gas detection performance, see Sec. 2.1.

3. Results

3.1 Data Postprocessing

The first step in evaluating the results involved synchronizing the sensor data with geocoordinates, excluding takeoff and landing periods, and subtracting background CH_4 and CO_2. A time-lag detection algorithm was then applied, utilizing detrending, normalization, and cross-correlation to account for potential sensor delays [4]. The performance of the post-processed sensor data is presented in Tab 1.

Table 1. Summary of CH_4/CO_2 concentrations

Flight	*#1*		*#2*		*#3*	
(ppm)	*min*	*max*	*min*	*max*	*min*	*max*
Snifer4D	600	700	-		600	1500
SJH-5	1.98	3700	-		1.98	3300
SCD30	484	697	430	6228	480	857
MHZ19B	-		430	7322	-	
Dräger PIR 7000	-		-		2	2000

Flight #1: Sniffer4D detected concentrations between 600 and 700 ppm, while SJH-5 ranged up to 3700 ppm, showing its higher sensitivity.
Flight #2: Only CO_2 measurements were taken, with the SCD30 recording a maximum of 6,228 ppm and the MH-Z19B reaching 7,322 ppm.
Flight #3: After adjusting the fan position from 0° to 80°, the Sniffer4D sensor reached 1,500 ppm, still significantly lower than the SJH-5's 3,300 ppm. The stationary CH_4 sensors, which initially detected no signal with the fan at 0°, registered up to 2,000 ppm when the fan's position was changed, but only the three closest sensors were affected.
To confirm the Sniffer4D's limitations, laboratory tests were conducted with the Sniffer4D in ambient air and a 2.5% CH_4 cylinder, which confirmed similar results: the sensor could not detect ambient air and reported lower than expected values for the 2.5% cylinder, aligning with the field data.

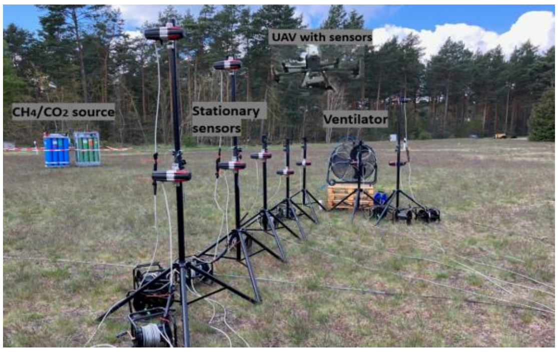

Fig. 2. Representation of the experimental setup

This comparison suggests that although we detected increased CH_4 and CO_2 concentrations, we were most likely not able to capture the whole extent of the plume during flights, especially with respect to its vertical extent. Moreover, we were unable to capture the entire plume with all sensors, highlighting potential limitations in the sensor placement, measurement limitations, and UAV's flight pattern. Factors such as UAV rotor downwash, fan position, sampling tube length, inlet type, and sensor position can all influence the results [3]. Additionally, Sniffer4D's factory calibration appears to be faulty and may have drifted over time, but this issue could be addressed with an external calibration, which is beyond the scope of this study.

Conclusions

This study demonstrated the feasibility of using UAV-mounted sensors for CH_4 and CO_2 plume detection in open-field conditions. Findings highlighted how sensor placement, fan angle adjustments, and sensor drift effects contribute to measurement variability, particularly for mobile setups. Future work should focus on refining sensor configurations and addressing environmental influences to enhance UAV-based gas detection systems' reliability.

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