

Scalable flux using chamber embedded integrated selective multigas sensing

Fabian Sievers¹, Moritz Zimmer¹, Álvaro Ortiz Pérez¹, Natalie Schütz¹, Stefan Palzer¹

¹ TU Dortmund, Professorship for Sensors, Otto-Hahn-Straße 8, 44227 Dortmund, Germany
stefan.palzer@tu-dortmund.de

Summary:

An integrated selective miniaturized multi-gas sensor embedded in a flux chamber enables real-time selective gas flux determination without sample extraction. Using frequency multiplexing multiple gas flux can be measured simultaneously with a single detector. Proving the independent gas flux measurement with a large cost reduction compared to conventional designs, a scalable platform for surface gas emission measurements was designed.

Keywords: photoacoustics, flux sensing, selective gas sensing, scalable flux chamber, sensor network

Introduction

Gas exchange between the Earth's surface and the atmosphere is a key component of global biogeochemical cycles regulating climate and ecosystem functioning. Soils and vegetation emit and consume gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) through respiration and microbial decomposition [1]. In agricultural systems, these fluxes are strongly influenced by management practices such as fertilization, irrigation, and livestock production. Because these processes vary significantly in space and time due to changes in soil moisture, temperature, biological activity, and management events, monitoring approaches with high temporal resolution and dense spatial coverage are required [1].

Currently, fluxes are mainly measured using eddy covariance systems or chamber-based approaches combined with gas chromatography or laser spectroscopy [2]. These methods often require gas sample extraction and complex instrumentation, limiting large-scale deployment. Recently the development of low-cost automated flux chambers with commercially available gas sensors directly inside the head volume have emerged [3]. Those increase complexity by using multiple sensors to achieve the simultaneous measurement of multiple gases and trade-off some selectivity and sensitivity by using lower quality sensors.

Here an approach using an integrated selective miniaturized multi-gas sensor [4] embedded in a chamber is shown to enable real-time gas flux determination without sample extraction. In this approach, gas fluxes are determined from real-time concentration gradients inside the

chamber, allowing continuous measurements with minimal system complexity. Such integrated sensing units provide a scalable foundation for dense chamber networks to monitor soil-atmosphere gas exchange across agricultural and natural landscapes.

Method

Fig. 1 depicts the used sensing setup. It uses two temperature-controlled light sources: L15895-0430CN and L15893-0330CN (Hamamatsu Photonics K. K., Japan) with wavelength of 4.3 and 3.3 μm . Amplitude modulation of the LED current with a sine wave of frequency 469 Hz and 541 Hz leads to sound wave generation at those frequencies according to the gas species.

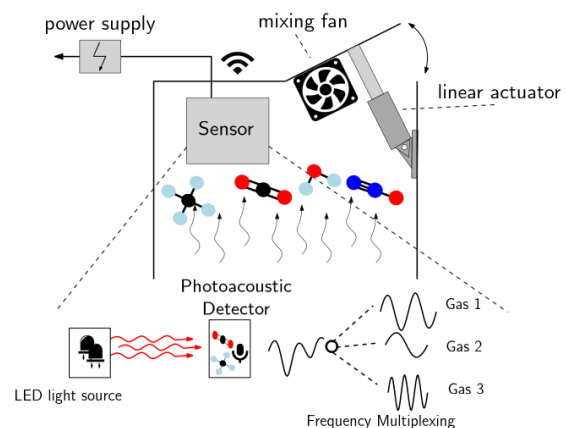


Fig. 1. Schematic Diagram of flux chamber. Multifrequency modulated LEDs excite photoacoustic signals according to each gas species.

The sensor has an absorption path length of 3 cm, where interaction between the gas mixture and light lead to an attenuation according to Beer-Lambert's law. Frequency multiplexing

allows selective multi-gas sensing without cross-sensitivity to humidity or other gases. The setup's compact size, allows sensor integration directly into the flux chamber. The vent, motorized by a linear actuator, can open and close the chamber automatically for intermediate ventilation. The gas sensor itself reports a measurement sample every 10 seconds for CO₂ and CH₄.

The sensor assembly includes a Wi-Fi capable ESP32 (Espressif Systems (Shanghai) Co., Ltd., China), reading and transmitting sensor data to an offsite database. It also controls the motor for the ventilation opening and reads data from an environmental sensor MS8607 (TE Connectivity plc, Ireland), recording air temperature, relative humidity and pressure.

Experimental

For evaluation the flux chamber was placed on top of cattle manure stored in a cut open IBC container. With a ventilation window of 5 minutes and a closed gas accumulation window of 20 minutes the continuous gas concentration inside the flux chamber was recorded for 11 days.

The flux is calculated using a closed chamber approach, meaning CO₂ and CH₄ concentration accumulate inside the closed chamber while being simultaneously measured by the sensor. The ventilation resets the gas concentration inside the chamber to the baseline, starting a new automated measurement cycle. The wireless interface allows for remote management and straight forward setup of multiple flux chambers in a wireless sensing network.

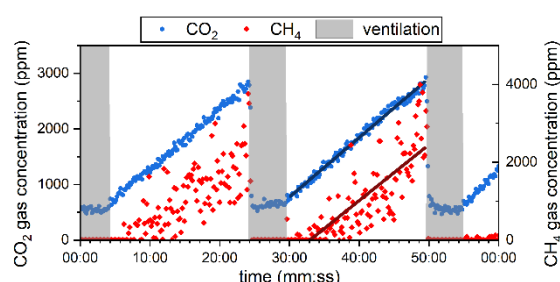


Fig. 2. Flow chamber gas concentration data for CO₂ and CH₄ with exemplary linear fits. The measurements were taken with a 5-minute ventilation window and 20 minutes of gas accumulation.

By applying a linear fit to the independent gas concentration data, while no ventilation occurs, the simultaneous gas flow for multiple gases can be determined independently (see Fig. 2).

Results

Applying the linear fitting method to the whole measurement period, the temporal trend of gas flux emitted from the substrate is created (see Fig. 3). By comparing flux data to the environmental sensor data recorded inside the chamber, investigation of the influence of environment

temperature, pressure and relative humidity is possible.

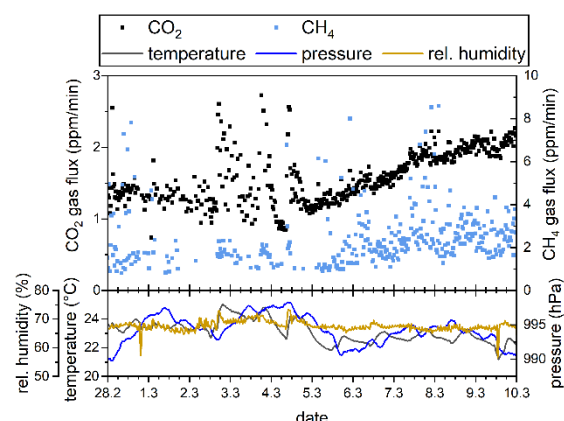


Fig. 3. Top: Flow data derived from flux chamber concentration measurements for CO₂ and CH₄. Bottom: Environmental sensor data during the measurement period.

Conclusion

By integrating a compact novel photoacoustic multi-gas sensor into a flux chamber, a revolutionary cost reducing sensing system for surface gas flux measurements was established, without compromising on selectivity. Cost reduction and integrating the sensor into the chamber, also adding wireless connectivity opens up opportunities for a scalable gas flux measurement network especially useful for dense large-scale soil emission examination. The multi-gas sensor would allow additional simultaneous gas detection of more gases without increasing complexity or cost of the sensor platform for measuring N₂O in soil emission, too.

References

- [1] M. Lackner, B. Sajjadi, W.-Y. Chen, eds., *Handbook of Climate Change Mitigation and Adaptation*. Springer International Publishing; Imprint Springer, Cham; 2022.
- [2] C. Oertel, J. Matschullat, K. Zurba, F. Zimmermann, S. Erasmí, Greenhouse gas emissions from soils—A review, *Geochemistry* 76, 327–352 (2016); doi: 10.1016/j.chemer.2016.04.002.
- [3] B. J. Archer, P. Casper, M. O. Gessner, AutoChamber : A broadly accessible 3D - printed floating chamber to automate measurements of greenhouse gas emissions from surface waters, *Methods in Ecology and Evolution* 17, 979–991 (2026); doi: 10.1111/2041-210x.70222.
- [4] G. Rodríguez Gutierrez, A. Ortiz Perez, S. Palzer, Integrated, Selective, Simultaneous Multigas Sensing Based on Nondispersive Infrared Spectroscopy-Type Photoacoustic Spectroscopy, *ACS sensors* 9, 23–28 (2024); doi: 10.1021/acssensors.3c01285.