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A UAV-based system for greenhouse gases and particulate measurement in livestock farms

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Abstract

Livestock production is a relevant anthropogenic source of gaseous and particulate pollutants. The increasing regulatory pressure to reduce emissions requires their systematic assessment. However, current methodologies for accurate GHGs, ammonia and particulate measurements at farm level demand extensive field and laboratory work, with high costs in terms of equipment and skilled personnel. In this context, the development of cost-effective methods for rapid and systematic monitoring of emissions is a key element. A UAV-based system was developed to measure gas (CO_2, CH_4, NH_3) and particulate matter ($PM_{2.5}$, PM_{10}) concentrations in the bottom atmospheric boundary layer. The system is founded on a flexible architecture and can be adapted to different operating environments. Prototype measuring units equipped with low-cost sensors were designed and implemented with the aim to identify emission hotspots. The units are designed to be employed both for ground measurements and for in-flight data collection on board of a customised UAV. Two flight missions were carried out in a dairy farm to evaluate the feasibility of ground and in-flight measurements. Ground units were positioned both inside and outside the building where dairy cows were housed, while simultaneous measurements were collected by the UAV. The results obtained showed that the prototype units are able to provide ground and in-flight measures of gases and PM, however further research is required to embed additional sensors and validate data across multiple state of the art methods.

Keywords: drone, sustainable livestock farming, GHG emissions, dairy farming

Introduction

Current environmental policies are targeting a green transition, which involves the reduction of greenhouse gases and air pollutants emissions. In this context, a key issue will be to develop cost-effective techniques ensuring a rapid and continuous assessment of air quality and of the distribution of pollutants in the atmosphere.

Atmospheric particulate matter (PM) is classified into inhalable particles, with an aerodynamic diameter less than or equal to 10 μm (PM_{10}), and in fine particle matter with an aerodynamic diameter lower than 2.5 μm ($PM_{2.5}$). Livestock production can emit considerable amounts of PM, which is a cause for air quality issues inside, but also outside livestock houses. Fine particles are known to be responsible for respiratory and cardiovascular diseases (Losacco & Perillo, 2018), thus a systematic assessment of particulate pollution is crucial for the protection of human and animal health.

Farming activities and livestock breeding cause also the emission of several gases, as CH_4, CO_2, N_2O, NH_3, especially during the digestive process and excreta decomposition. The emissions of greenhouse gases contribute notably to global warming, while NH_3 can cause respiratory diseases, damage terrestrial vegetation and be a precursor of secondary $PM_{2.5}$. Obtaining punctual and regular measures of gas concentrations at farm scale represents a crucial goal to assess the efficacy of mitigation practices and, ultimately, to improve the management of GHGs emissions.

In the last decade, UAV-based monitoring systems have emerged as an alternative or complementary technique to traditional ground-based detectors. UAVs represent a new frontier for atmospheric chemistry research; moreover, they are being increasingly applied in the fields of industrial emission monitoring and precision agriculture (Burgués & Marco, 2020). Drones equipped with gas and/or PM sensors have been employed to measure the emissions at point sources or to investigate the vertical profile of pollutants concentrations in the atmospheric boundary layer. Examples of the assessment of emissions at pollutant sources with drone-based measurements regard the quantification of methane emissions from oil and gas infrastructures (Smith *et al.*, 2016) and landfills (Emran *et al.*, 2017) or multipollutant determination in open burnings (Aurell *et al.*, 2017). Vertical profiles were assessed using multicopters equipped with particulate (Kuuluvainen *et al.*, 2018) and gas (Cabassi *et al.*, 2022; Gu *et al.*, 2018) sensors both in urban and in rural environment. A variety of small and low-cost gas sensors (amperometric gas sensors, metal oxide semiconductor sensors, non-dispersive infrared sensors, and photoionization detectors) were used on UAVs to detect or measure leaks, concentrations or flux of a wide array of gases (e.g. CO, CO_2, NO_x, N_2O, O_3, NH_3) and VOCs. In the field of precision agriculture, however, research is still pioneering. Drones equipped with environmental sensors have been proposed as an option to automate certain agricultural tasks, such as monitoring climate variables in greenhouses (Roldán *et al.*, 2015) or evaluating fruit maturity (Valente *et al.*, 2019), but their potential use for gas pollutants and particulate monitoring has still to be assessed. In this framework, the research aimed to develop and test a UAV-based system to assess PM, GHGs and ammonia hotspots in the context of livestock farming. The goal is to provide a rapid and real-time system for emission monitoring of livestock buildings, manure and feed stores. A prototype UAV-based and ground measurement system was developed, implemented and tested to assess the feasibility of ground and in-flight measurements.

Material and methods

System design

The project is based on a modular design with flexible architecture and can be adapted to a wide range of operational fields. The design is structured in four layers (Figure 1). Layer 1 (sensor layer) concerns the sensors and the collection of all measurements; layer 2 (network layer) regards the transmission of data collected by the sensors towards the storage system; layer 3 (service layer) represents the storage system where measurements are collected and analysed; layer 4 (application layer) provides a tool for data presentation where measurements can be visualised through a dashboard.

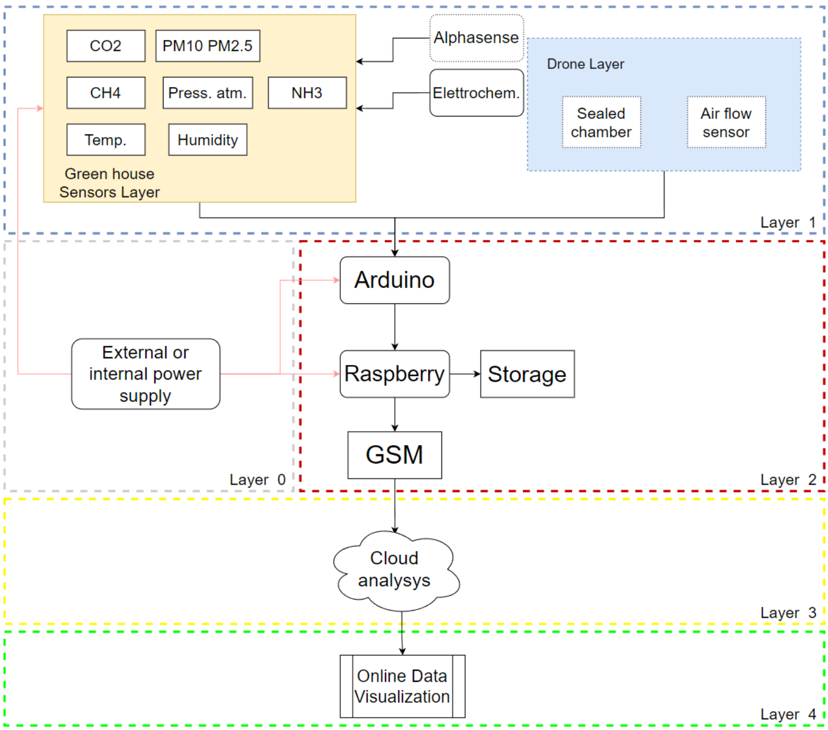

Figure 1: Layer organisation of the system architecture

The whole project design comprises four modules: gas and particulate measurement units, a UAV, a server and a dashboard. For the purposes of this research, aiming to assess the feasibility of ground and in-flight measurements, the first two models were developed and tested. The sensor layer and network layer were embedded in a prototype ground-based measurement unit and in a miniaturised version on board of a drone (Figure 2). The measurement unit on the UAV was deployed on a tube to prevent the effects of the airflow and turbulence generated by the rotors on gases and PM measurements. The drone (3DR Solo; 45.7 x 45.7 x 25.4 cm; weight: 1.5 kg) was a quadricopter. The units were provided with multisensor boards with ARM Cortex M0+ processor, ATM2560 microcontroller for data processing and transmission and Raspberry Pi Compute Module. They integrated data from all onboard sensors, tagged data with timestamp and, for the UAV module, geolocation in real time, while ground-based units were manually georeferenced with a GPS-GNSS receiver.

Air pollutant sensors

Low-cost commercial sensors were selected to meet the goal of air quality monitoring in a livestock farming environment, according to a Life Cycle Assessment (LCA) procedure. Target pollutants were particulate matter ($PM_{2.5}$, PM_{10}), NH_3, CH_4 and CO_2. Additionally, temperature, relative humidity and atmospheric pressure sensors were embedded in each unit. Detailed technical characteristics of the sensors are summarised in Table 1.

Field tests

The ground and the UAV measurement units were tested in a commercial dairy farm located in Tuscany, Central Italy, where 450 Holstein Friesian cows were housed.

Table 1: Name, type, measurement and operative range of the tested sensors

Target measurement	Sensor name	Type of sensor	Measurement range	Operative range	
				Temperature (°C)	Relative humidity (%RH)
$PM_{2.5}$,PM_{10} (μg m-³)	SDS011	Optical	0 to 999.9	- 20 to 60	0 to 90
NH_3 (ppm)	MICS 6814	Electrochemical	0 to 100	- 30 to 50	15 to 95
CH_4(ppm)	IRC-AT	Electrochemical	200 to 10000	- 20 to 50	0 to 95
CO_2 (ppm)	SCD30	NDIR	400 to 10000	- 40 to 70	0 to 95
Temperature, %RH	SHT40	CMOSens	- 40 to 90 0 to 100	- 40 to 125	0 to 100
Atmospheric pressure (hPa)	BMP280	CMOSens	300 to 1100	- 40 to 85	0 to 100

The field tests on the ground and on the UAV unit were conducted during two days in March and July 2021. In each session, the ground station was deployed in five locations: inside (I) the cubicle barn, in the central feeding alley, and outside (O) the barn, at the four sides of the building. Environmental, gas and particulate measurements were recorded for on average 20 minutes at each location; overall, 788 records were collected. Two flights were conducted at 31.3 ± 0.9 m a.g.l. over the farming site; the first measurement session (March 2021) was carried out during a 7 minutes non-stop flight, where 175 records were collected while the drone was moving along the chosen path (Figure 3). In the second measurement session (July 2021) the flight mission was planned to obtain static measurements: the drone stopped at each waypoint where measurements were taken. To cover the same area over the farm, two consecutive flights were conducted for 24 minutes in total, and 451 records were collected.

Figure 2: The '3DR Solo' drone equipped with the miniaturised prototype measurement unit

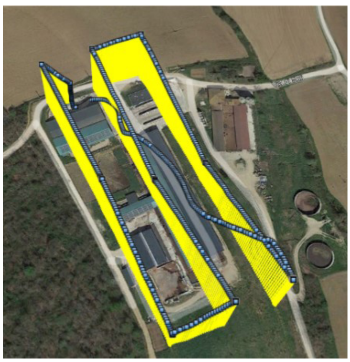

Figure 3: Path followed by the UAV during the 1st field session

At the same time of ground and in-flight measurements, representative samples of air inside and outside the main building were collected in sample bags selected to ensure good stability of the target gases. Sampled air was analysed by Gas Chromatography (GC) to determine methane and carbon dioxide concentrations. The results were used to assess the adequacy of measures from the prototype units.

Results and Discussion

Table 2: Gas and PM measurements (minimum, maximum, average ± standard deviation) collected by the prototype UAV unit and ground unit (O: outside the cubicle barn; I: inside the cubicle barn).

	UAV (March 2021)	UAV (July 2021)	Ground (March 2021)	Ground (July 2021)
Min - Max CO_2 (ppm)	-	0 - 40000	O: 3.10 - 30.34 I: 4.56 - 37.00	O: 401.00 - 475.00 I: 442.00 - 504.00
Ave ± S.D. CO_2 (ppm)	-	3187.49 ± 7440.68	O: 6.92 ± 4.08 I: 15.88 ± 12.02	O: 426.20 ± 22.31 I: 467.81 ± 15.38
Min - Max CH_4 (ppm)	0.75 - 4.44	0.12 - 26.8	O: 1.62 - 11.40 I: 1.64 - 10.69	-
Ave ± S.D. CH_4 (ppm)	2.48 ± 0.87	5.24 ± 5.77	O: 2.52 ± 1.50 I: 4.49 ± 3.26	-
Min - Max NH_3 (ppm)	-	0.47 - 1.10	O: 0.22 - 0.65 I: 0.20 - 0.43	-
Ave ± S.D. NH_3 (ppm)	-	0.99 ± 0.21	O: 0.42 ± 0.10 I: 0.27 ± 0.04	-
Min - Max $PM_{2.5}$ (µg m^{-3})	4.60 - 327.60	2.00 - 249.30	O: 1.50 - 4.60 I: 1.30 - 2.90	O: 4.10 - 10.40 I: 5.00 - 14.00
Ave ± S.D. $PM_{2.5}$ (µg m^{-3})	153.16 ± 126.83	96.41 ± 70.47	O: 2.82 ± 0.77 I: 1.65 ± 0.27	O: 5.10 ± 0.89 I: 6.43 ± 1.99
Min - Max PM_{10} (µg m^{-3})	7.56 - 327.48	3.30 - 715.70	O :2.00 - 14.70 I: 1.60 - 21.20	O: 4.50 - 71.00 I: 5.60 - 98.80
Ave ± S.D. PM_{10} (µg m^{-3})	123.50 ± 100.07	206.81 ± 197.43	O: 5.03 ± 1.87 I: 4.45 ± 3.83	O: 10.30 ± 8.61 I: 17.38 ± 20.32

The first field tests on the ground and UAV measurement units demonstrated the technical feasibility of the prototype modules. The gas and particulate concentration measurements collected during the two surveys with UAV and ground units are summarized in Table 2. Data collected in March 2021 by the CO_2 sensor in the first ground unit prototype (O: 6.92 ppm; I: 15.88 ppm) were not plausible compared to the concentration measurements obtained with GC analysis of sampled air (O: 448.38 ppm; I: 525.34 ppm). Thus, a different commercial sensor was selected for the second version of the prototype unit (July 2021). The new sensor revealed concentration values (O: 426.20 ppm; I: 467.81 ppm) that were comparable to those measured with GC (O: 486.01 ppm; I: 608.80 ppm), although lower. The same sensor was deployed on the UAV, however results were not reliable due to technical reasons related to the sensor placement on the unit. The methane electrochemical sensor on the ground yielded plausible, yet lower, values (O: 2.52 ppm; I: 4.49 ppm) compared to those measured in sampled air (O: 3.24 ppm; I: 8.50 ppm). With the aim of improving the accuracy of the system, the CH_4 and NH_3 sensors were removed from the second version of the prototype unit and newer commercial options will be evaluated. Measurements collected at 30 m a.g.l. with the UAV unit yielded values that were consistent with those measured by the ground unit, suggesting that in-flight gas and particulate assessment is a promising technique.

Conclusions

The prototype system described in this work represents a first attempt to evaluate the feasibility of a low-cost and real-time air quality monitoring in livestock farms. Technical adjustments will be needed to optimize costs, accuracy of measures and size of the units; moreover, further laboratory and field trials will be necessary to select the best available sensor options on the market, calibrate the sensors in a lab environment and to assess the accuracy of measures in the field. Despite improvements are required before its use for research or farm management, the results confirm the feasibility of the system and set the basis for a rapid and smart tool to monitor GHGs, ammonia and particulate emissions in livestock farms.

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References

Aurell J., Mitchell W., Chirayath V., Jonsson J., Tabor D. and Gullett B. (2017). Field determination of multipollutant, open area combustion source emission factors with a hexacopter unmanned aerial vehicle. *Atmospheric Environment* 166, 433-440.

Burgués J. and Marco S. (2020). Environmental chemical sensing using small drones: A review. *Science of the Total Enviroment* 748, 141172.

Cabassi J., Lazzaroni M., Giannini L., Mariottini D., Nisi B., Rappuoli D. and Vaselli O. (2022). Continuous and near real-time measurements of gaseous elemental mercury (GEM) from an Unmanned Aerial Vehicle: A new approach to investigate the 3D distribution of GEM in the lower atmosphere. *Chemosphere* 288, 132547.

Emran B. J., Tannant D. D. and Najjaran H. (2017). Low-altitude aerial methane concentration mapping. *Remote Sensing* 9(8), 823.

Gu Q., Michanowicz D.R. and Jia, C. (2018). Developing a modular unmanned aerial vehicle (UAV) platform for air pollution profiling. *Sensors* 18, 4363.

Kuuluvainen H., Poikkimäki M., Järvinen A., Kuula J., Irjala M., Dal Maso M., Keskinen J., Timonen H., Niemi J. and Rönkkö T. (2018). Vertical profiles of lung deposited surface area concentration of particulate matter measured with a drone in a street canyon. *Environmental Science and Pollution Research* 241, 96–105.

Losacco C. and Perillo A. (2018). Particulate matter air pollution and respiratory impact on humans and animals. *Environmental Science and Pollution Research* 25(34), 33901-33910.

Roldán J. J., Joossen G., Sanz D., Del Cerro J. and Barrientos A. (2015). Mini-UAV based sensory system for measuring environmental variables in greenhouses. *Sensors* 15(2), 3334-3350.

Smith B., John G., Stark B., Christensen L.E. and Chen Y. (2016). Applicability of unmanned aerial systems for leak detection. In: 2016 International Conference on Unmanned Aircraft Systems (ICUAS), pp. 1220–1227.

Valente J., Almeida R. and Kooistra L. (2019). A Comprehensive Study of the Potential Application of Flying Ethylene-Sensitive Sensors for Ripeness Detection in Apple Orchards. *Sensors* 19(2), 372.