Mapping atmospheric concentration of gas and particulate matter in livestock farms using drone-based measurements

Valentina Becciolini [1], Marco Merlini [1], Gabriele Coletti [2], Leonardo Conti [1], Diego Bedin Marin [1], Alessio Mattia [1], Giuseppe Rossi [1], Ugo Rossi [2], Matteo Barbari [1*]

[1] Department of Agriculture, Food, Environment and Forestry (DAGRI), University of Florence, Florence, 50144, Italy

[2] Project & Design s.r.l.s., Florence, 50142, Italy

* Corresponding author. Email: matteo.barbari@unifi.it

Abstract

Unmanned Aerial Vehicles (UAVs) represent the new frontier for gas monitoring in the atmospheric boundary layer in multiple sectors. An interesting perspective is the use of in-flight measurements to monitor pollutants emissions from livestock farms, however this application is still pioneering.

A system for measuring greenhouse gases and particulate matter concentrations at ground and in-flight was developed, to provide a tool to rapidly detect and visualize emission hotspots around housing facilities, manure and feed storages. The system is based on small-sized prototypal multi-sensor system (MS). MS can be used both for ground monitoring and for installation on multirotor drones. The units are equipped with sensors for measuring air pollutants and environmental conditions. Georeferenced data collected by the MS are available in real time and can be downloaded or visualized on a graphic interface.

A feasibility test was conducted on a dairy farm located in Tuscany, Central Italy, to assess the correct functioning of the system and to explore the possibilities of mapping gas and particulate concentrations.

Keywords: Unmanned Aerial Vehicles, gaseous and particulate emissions, precision agriculture, sustainability.

1. Introduction

The use of UAVs to assess and locate sources of gaseous and particulate emissions is rapidly increasing in several fields. Apart from quantitatively characterising the levels of air pollution, a promising application is the possibility of rapidly obtain concentration maps, i.e. building spatial representations of pollutants concentrations in a defined area based on a set of spatially distributed sensor measurements (Burgués and Marco, 2020). Different approaches have been employed, e.g. two-dimensional mapping using spatial interpolation (Burgués et al. 2021, Rutkauskas et al. 2019) or 3D mapping strategies (Bing et al. 2015). Our study aimed to explore and assess the possibilities of mapping air pollutants concentrations measured in the lower atmospheric boundary layer in GIS environment, using a prototype multi-sensor system, as tool to rapidly locate emission sources in a farming context.

2. Materials and Methods

A prototype multi-sensor system (MS) was developed. The system was designed to monitor air quality at fixed ground points and in-flight, as payload on a multirotor drone. This work was focused on the use of multi-sensor systems for UAV-based measurement of gas and particulate matter in dairy farms and their mapping. The study reports the results of a measurement campaign carried out in a commercial dairy farm located in Tuscany, Central Italy. The farm hosted 65 Holstein Friesian lactating cows (herd size: 135 heads) housed in a cubicle pen inside the main barn, while dry cows and heifers were housed in pens with deep straw bedding in the same building. Slurry produced in the barn was mechanically separated after its removal from the barn. Both the solid and the liquid fraction were stored in uncovered facilities.

2.1. A multi-sensor system for air quality monitoring

The prototype multi-sensor system built for this study was designed to be deployed both at ground, for static measurements, and as payload on small multirotor drones, for in-flight air quality monitoring. The multi-sensor system had a total weight of 0.75 kg and small volume (120x100x67 mm). The system embeds a set of sensors for gas (CH_4, CO_2, NH_3, NO, NO_2, SO_2) and particulate ($PM_{2.5}$, PM_{10}) measurement. Moreover, additional sensors for recording environmental conditions (temperature, relative humidity, atmospheric pressure) were included. A ESP32® microcontroller and a Raspberry Pi® microprocessor were used for data collection, processing and storage. Data were collected with a frequency of 1 record every 5 seconds.

2.2. UAV-based measurements

The multi-sensor system was deployed on top of a quadrotor drone (DJI® Matrice 300 RTK). A flight mission was planned at 30 metres a.g.l., covering the entire area of the barn and manure storage facilities, with predefined waypoints. The total duration of the flight was 10 minutes and the total number of records collected for each parameter (gas concentration, particulate concentration, environmental variables) was 86. Records were timestamped, linked to their spatial position with centimetre accuracy and merged in a comprehensive dataset.

2.3. Mapping tools

The georeferenced dataset was processed in GIS environment (QGIS® 3.22.5) and converted into a point vector layer. For each air quality variable (i.e. gases and particulate matter), data points were interpolated basing on air pollutant concentrations measured by the MS, using the Inverse Distance Weighted (IDW) method. The IDW processing tool in QGIS returns a raster layer interpolation map. Gas and particulate concentration maps were produced for all measured pollutants and overlapped to satellite images of the farm.

3. Results and Discussion

During the flight, the average air temperature recorded by the MS was 28.06 ± 0.26 °C, with an average relative humidity of 59.90 ± 0.82 %. All gas and particulate sensors yielded measurements of concentration within the expected ranges, with the exception of the NH_3 sensor, whose detection limit was above the concentrations present at the experimental site, and the CH_4 sensor which was able to capture variations in the air concentration of the gas but provided measurements considerably higher than expected. Detailed results of the in-flight measurements are reported in Becciolini et al. (2022).

In this work, concentration maps of PM_{10} (Figure 1) and carbon dioxide (Figure 2) are reported. Air concentrations of PM_{10} ranged from 5.90 to 9.80 μg m^{-3}.

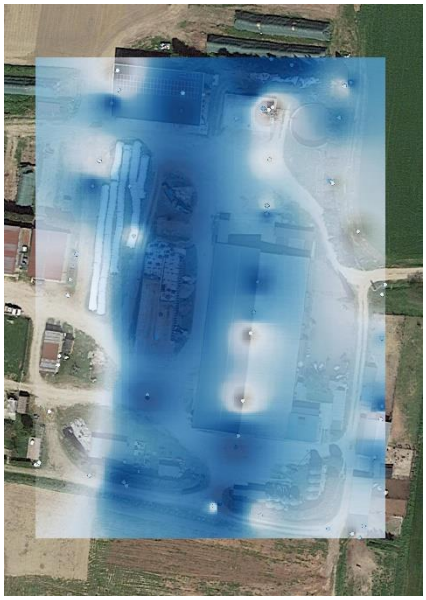

Figure 1. Particulate matter (PM_{10}) concentration map obtained by Inverse Distance Weighted interpolation method.

The interpolation map (Figure 1) allowed to locate sites characterised by higher concentrations (dark blue), which corresponded to the areas alongside the barn and manure storages. The result appears significant given that, during the flight, the unifeed wagon was operating around the barn for feed preparation.

Air concentration of CO_2 ranged from 389 to 469 ppm. The interpolation map (Figure 2) highlighted higher concentrations (dark orange) over the barn and over the manure storage areas.

Although two-dimensional mapping solutions, as interpolation methods available in GIS environment, are not able to account for the effects of air speed and direction on gas and particulate dispersion in the bottom atmospheric layer, they could represent a tool to rapidly identify and locate emission sources in a farming context. This opportunity is dependent on the ability to record multi-species gas and particulate data rapidly with small multirotor drones, which represent an innovative approach resulting from this research.

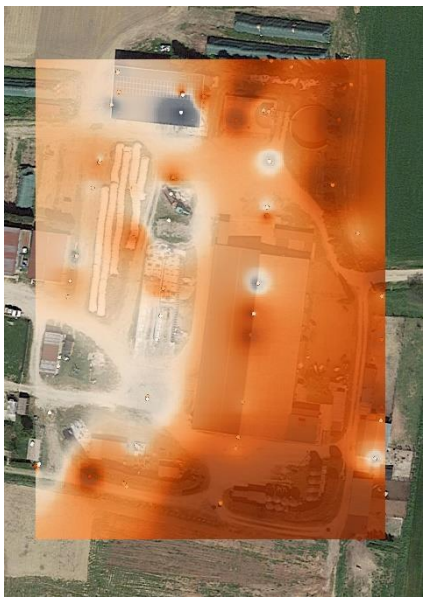

Figure 2. Carbon dioxide concentration map obtained by Inverse Distance Weighted interpolation method.

4. Conclusions

The prototype UAV-based multi-sensor system proved to be a promising technology both for measuring gas and particulate concentrations at the farm level and to provide data that could be easily implemented in GIS environment to derive concentration maps, allowing to locate pollutant hotspots.

Acknowledgements

The research (Project ID 39274 CCCFarming) was funded within the ERA-NETs FACCE ERA-GAS, ERA-NET SusAn reasearch program by the Ministry of Agricultural, Food and Forestry Policies, Italy.

References

Becciolini, V., Conti, L., Rossi, G., Bedin, M. G., Merlini, M., Coletti, G., Rossi, U., Barbari, M., 2022. Real-time measurements of gaseous and particulate emissions from livestock buildings and manure stores with novel UAV-based system. In *12th AIIA Conference - Biosystems engineering towards the Green Deal.* Palermo, Italy, September 19-22. (*In press*)

Bing, L., Qing-Hao, M., Jia-Ying, W., Biao, S., Ying, W., 2015. Three-dimensional gas distribution mapping with a micro-drone. pp. 6011-6015. *In 2015 34th Chinese Control Conference, CCC*. Hangzhou, China, July 28-30. IEEE.

Burgués, J., Marco, S., 2020. Environmental chemical sensing using small drones: A review. Science of The Total Environment, 748: 141172.

Burgués, J., Esclapez, M. D., Doñate, S., Pastor, L., Marco, S., 2021. Aerial mapping of odorous gases in a wastewater treatment plant using a small drone. Remote Sensing, 13(9): 1757.

Rutkauskas, M., Asenov, M., Ramamoorthy, S., Reid, D. T., 2019. Autonomous multi-species environmental gas sensing using drone-based Fourier-transform infrared spectroscopy. Optics Express, 27(7): 9578-9587.