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CO_2 monitoring through pigeon-borne miniaturized sensors: the case study of Rome (Italy)

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ABSTRACT

The deterioration of air quality is today a source of growing concern due to the implications on human health and ecosystems, especially in metropolises and high-density built-up areas, where an ever-increasing fraction of the global population resides. In addition to greenhouse gases and atmospheric pollutants, such as atmospheric particulate matter, benzene, and nitrogen oxides, regulated by international protocols, carbon dioxide (CO_2) has recently been included among the gases responsible for climate change (Coutts et al., 2007), with serious consequences for human health (Intergovernmental Panel on Climate Change, 2021). In urban areas, the concentration of CO_2 is traditionally monitored by ground-based, point stations, the measures of which cannot be considered as representative of the entire Planetary Boundary Layer (PBL), i.e., the layer of atmosphere closest to the ground.

In this context, atmospheric monitoring through small, dedicated air samplers attachable to birds freely moving in the urban environment might represent an innovative technique. The use of birds could be convenient, especially in cities, where the use of drones and the release of atmospheric probes are restricted and where most of the anthropogenic CO_2 sources are located. The development of miniaturized sensors is pushing the frontiers of animal ecology through biologging, i.e., the use of devices collecting data about movement, behaviour, physiology of the animals and the abiotic parameters of the environment in which they move.

Here, an innovative miniaturized active air sampler wearable by free-flying birds is presented and tested. The device consists of a set of calibrated atmospheric sensors for high spatial-temporal resolution measurements of chemical and physical parameters, such as CO_2 concentration, atmospheric pressure, temperature, and relative humidity. Such devices were applied to homing pigeons (*Columba livia domestica*, Figure 1) to carry out measurements within the urban PBL.

A field campaign, carried out from January to June 2021, involved the repeated release of homing pigeons from downtown Rome (Italy), to sample the air on their way back to the loft, located in a rural area out of the city. During their homeward journey, the birds were flying at variable altitudes across areas with different degrees of urbanization.

Figure 1
Photograph of the device attached on a homing pigeon.

DESIGNS AND DEVELOPMENT OF AIR SAMPLERS

The development of the miniaturized air samplers used in the present study is carried out in collaboration with a private company specialized in devices for animal tracking (Technosmart Europe S.r.l., Rome, Italy). The device is based on the integration of a set of sensors on an existing GPS data logger with a wire antenna powered by a 200 mA LIPO battery (AxyTrek).
The boards and the battery are arranged in a flat and aerodynamic design (50 mm × 20 mm) to reduce possible drag to the birds in flight. The weight of the complete system is 14.6 g, including the battery, and therefore at the limit of the recommended 3% of the bird's body mass, considering that the pigeons weighed around 450 g. In any case, the units are used for short-term deployments of 1–2 h.

ATMOSPHERIC SENSORS

BME280, Bosch Sensortec, Reutlingen, Germany

- barometric pressure (operating range: 300-1100 hPa; accuracy: ± 1 hPa)
- temperature (accuracy: ± 1 °C)
- relative humidity (accuracy: ± 3 %)

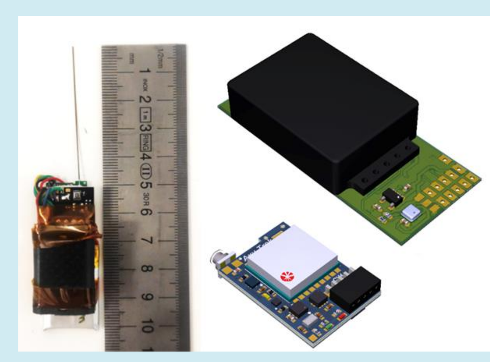

Figure 2
Photograph (left) and schematic view (top right: CO_2 sensor on PCB, bottom right: AxyTrek data logger) of the miniaturized data logger.

CO_2 SENSOR

Sense air, Sunrise AB, Delsbo, Sweden

- size: 33.5(L) x 19.7(W) x 11.5(H) mm^3
- weight: 5 g
- operating range: 400-5000 ppm
- Accuracy: ±30 ppm

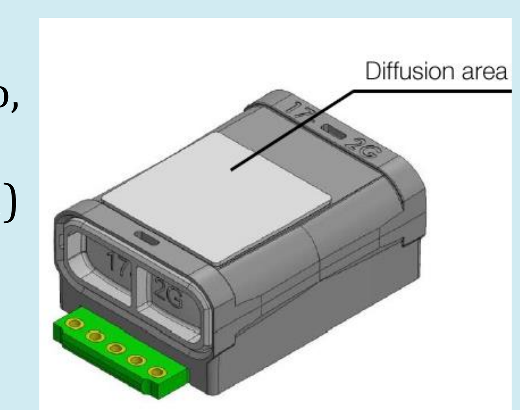

Figure 3
CO_2 sensor with the gas diffusion area represented by the white membrane.

SENSORS CALIBRATION

For this study, being the data collected only for short periods during homing flights, we ensured different tags have similar sensitivity. CO_2 sensors were placed indoors for a week-long test, close to an open window, in a room occasionally occupied, increasing CO_2 levels significantly.
As shown in Figure 4, the two sensors tested show very similar sensitivity, with comparable responses to variations in CO_2 concentration in the test room. Granger tests were performed over all the combinations of sensors, testing whether one-time series predicted the other and vice versa. All tests were highly significant ($p < 0.001$), meaning that every timeseries is predictable by the other.
CO_2 concentrations were acquired with a sampling frequency of 0.42 Hz. This is the default value for the Sense air Sunrise, which collects eight samples per measurement. A sample takes less than 300 ms, producing a period of 2.4 s for each complete measurement. The response time is reported to be less than 30 s.
Di Bernardino et al., 2022

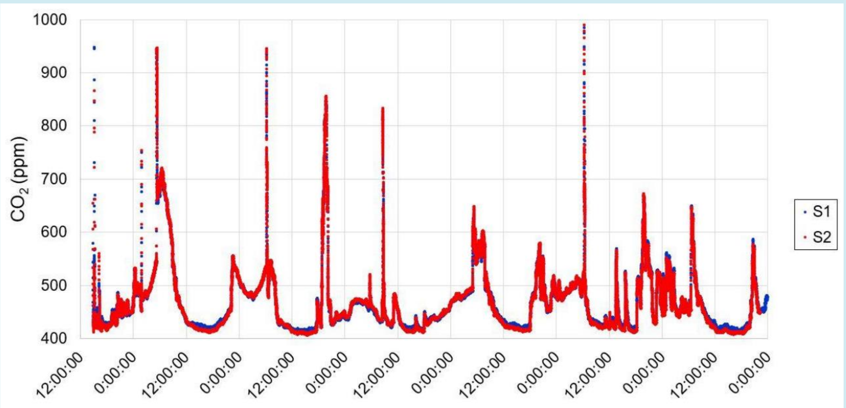

Figure 4
Temporal trend of CO_2 concentration during the calibration test.

FIELD CAMPAIGN

- Release: Sapienza University campus (41.90° N, 12.51° E)
- Arrival: loft (41.58° N, 12.37° E)
- Sampling frequency (atmospheric parameters): 1 Hz
- Sampling frequency (CO_2): 2 Hz

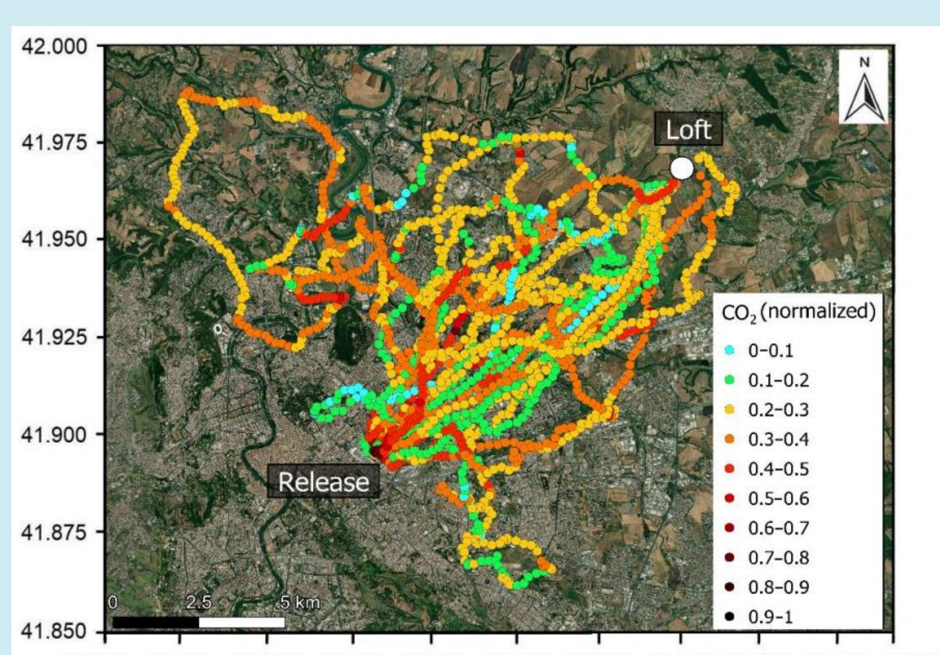

Figure 5
Map of pigeon flights tracks. The colour intensity depicts the concentration measured after normalization.

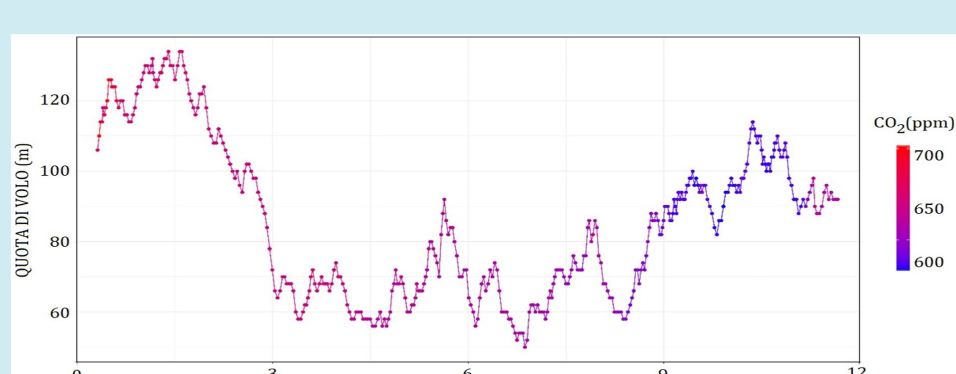

Figure 6
Example of CO_2 concentration profile as a function of height and distance from the release point.

Date	Time (UTC)		Flight		CO_2 concentration (ppm)		
	Release	Arrival	Duration (min)	Distance (km)	Mean	Min.	Max.
21/01/2021	08:22	08:39	17.0	16.6	613	533	797
26/01/2021	08:29	09:07	37.7	27.0	567	498	725
28/01/2021	07:55	08:44	48.8	14.5	659	544	798
29/01/2021	08:15	11:37	202.1	47.8	562	457	797
29/01/2021	08:16	08:40	24.5	23.2	655	578	799
05/02/2021	09:09	09:39	30.2	17.5	637	572	777
05/02/2021	09:09	10:24	75.4	19.7	584	489	786
08/02/2021	08:40	10:37	116.8	14.1	565	452	798
19/03/2021	09:02	09:25	23.0	18.7	497	476	576
01/04/2021	07:04	12:13	309.2	25.1	560	504	765
07/04/2021	07:06	12:53	347.6	26.0	465	410	558
07/04/2021	07:01	09:37	156.0	38.3	531	481	696
09/04/2021	08:57	09:06	8.5	9.4	455	436	481
09/04/2021	08:52	09:06	14.2	15.2	578	550	751
21/04/2021	07:19	07:34	15.4	14.0	585	514	792
23/04/2021	08:15	08:28	13	12.8	614	566	702
04/05/2021	07:26	08:09	42.6	11.1	516	472	618
06/05/2021	07:18	07:30	12.6	13.8	565	516	688
07/05/2021	07:16	09:00	104.6	14.0	571	436	799
07/05/2021	07:26	07:38	11.9	13.7	507	493	547
11/05/2021	07:18	08:40	81.9	15.1	586	492	730
11/05/2021	07:18	07:35	17	12.7	572	478	699
15/06/2021	11:19	16:20	1740.3	82.7	673	528	799
15/06/2021	06:18	14:49	510.2	35.8	566	439	793
18/06/2021	06:35	07:55	79.9	16.3	626	538	790

CONCLUSIONS

The air sampler developed in this study represents a low-cost, environmentally friendly, easy-to-use tool for environmental monitoring, providing enhanced observation and interpretation opportunities, with minimal effects on the well-being of the birds.
This research can be considered as a starting point for further studies, aimed at developing miniaturized sensors for the study of other atmospheric gases, wearable by other bird species (i.e., gulls) with very limited impact on their well-being, capable of flying at higher altitudes and over greater distances than pigeons.

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- Di Bernardino, A., Jennings, V., & Dell'Omo, G. (2022). Bird-Borne Samplers for Monitoring CO2 and Atmospheric Physical Parameters. Remote Sensing, 14(19), 4876.