Article

ARIA: instrumented drone for air pollution monitoring

Giacomo Colombatti [1,*], Alessio Aboudan [1], Carlo Bettanini [2], Riccardo Dal Moro[2], Gian Marco Bolla[2], Alice Mencarelli[2], Antonio Gobbo[2] and Enrico C. Lorenzini[2]

[1] CISAS *Giuseppe Colombo* - Università degli Studi di Padova; Padova, Italy
[2] DII *Dipartimento Ingegneria Industriale*- Università degli Studi di Padova; Padova, Italy
* Correspondence: giacomo.colombatti@unipd.it; Tel.: +390498276848

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Abstract: Environmental pollution awareness has increased in the last years due to the fact that not enough has been done, up to now, to reduce pollution. In particular, the need to monitor air quality in urban and industrial areas has shown to be an urgent necessity. Furthermore the measurement of pollution is usually performed via stationary ground-mounted air pollution stations. Our research is aiming to develop a monitoring system that allows for multiple contemporary measurements of areas at different heights with improved convenience and flexibility. The ARIA project solution proposed in this paper is a low-cost monitoring system based on COTS sensors and on multiple cheap drone platforms. The system is equipped with $PM_{2.5}$ and PM_{10} sensors for monitoring the particulate concentration at different altitude and trace the diffusion of air pollutants; several other gas sensors (such as NO, NO_2, CO, etc.) are present on a vertical stub on the UAV platform in order to sense unperturbed air. The use of UAVs allows to fly at different altitudes and have a moving station that allows to build a 3D map of pollutants in a specific area. The map is very useful both for urban and industrial areas; in the first case it is useful for monitoring the air at different heights around buildings and populated areas and in the latter case it can monitor the 3D environment around a possible polluting plant. The ARIA project shows the relevance of a custom, simple and lightweight UAV equipped with mobile monitoring devices as an effective, versatile, and unconventional mean to collect three dimensional contemporary air pollutant concentration data. The system platform is presented and the first test flight is shown.

Keywords: Air pollution; UAV; network; 3D map

1. Introduction

Air pollution is caused by different typologies of gas pollutants that are present in the first meters (<150 m) of the atmosphere and cause therefore damages to humans and environment. As air pollution is becoming the largest environmental health risk, the monitoring of air quality has drawn much attention in both laboratory studies and specific field tests and data collection campaigns. Government agencies and local administrations have, generally, provided and used monitoring stations on dedicated sites in cities and urban areas. It has widely been demonstrated that contaminants in the air are mostly caused by exhaust emissions from industrial production and daily activities of humans, such as driving fuel automobiles and rubbish dumps fires [?] [?]. Thanks to continuous awareness of the population, people, even the young generations, and maybe especially them, have a relatively high attention in pollution-related issues (i.e. "the friday for future" strikes 2019 events [?]). Usually the studies have been conducted using fixed stations that are very reliable but produce only coarse-grained 2D monitoring, with several kilometers between two monitoring stations; or the stations monitor the same local area for long periods.

Other approaches show that applications using simple system of sensors have been developed to monitor the fine-grained air quality using densely deployed sensors [?], [?]. In any case, the fixed sensor station may achieve high precision, but have high cost and require maintenance and suffer especially for lack of mobility. For these reasons in the last years mobile devices or vehicles, such as phones, cars, balloons are used to carry sensors [?], [?] and [?].

The usage of Unmanned Aerial Vehicles (UAVs) has been particularly rich in the latest years [?] and [?]. Due to the flexibility, mobility and affordable cost of drones, their utilisation is exponentially increasing also by private citizens or academic institutions. Current monitoring systems are not able to satisfy every need of modern cities and industrial areas and UAVs are valuable supporting elements in this scenario.

In terms of urban conditions, which is the main subject of the present study, UAVs can be used to measure environmental parameters such as illumination, as done in [?] [?] [?], wind speed, temperature, humidity, air quality [?] and much more. In any case, for a complete analysis, both ground sensing and aerial sensing are necessary to provide 3D mapping and gas profiling. In our ARIA project, we equipped with the same set of sensors the devices that execute sensing on the ground, and the systems that execute aerial sensing on board the UAV. The fixed ground sensing suite is able to collect data in a continuous way, but the air quality of the higher levels of air off the ground cannot be detected, so the contemporary use of drones is mandatory. Aerial sensing, on the contrary, is able to sense the air quality off the ground, but it cannot be executed for very long periods due to the high consumption of battery power and human time. By merging the potentialities of these two systems of sensing suites, a better set of data can be collected [?]. A trade off on the possible sensors and UAVs has been performed and quadcopters are the preferred platform for monitoring because of their simplicity, low cost and hovering capabilities. On the contrary a possible bias of data is due to the the influence of air jets created by the rotor rotation or by the electromagnetic field generated by the antennas present on board. The problem of choosing the best location of the sensors is examined in [?] based on the physical structure of the drones. Our approach is to use an extension on which we fix the sensors in order to suck the air away of the main air jets.

ARIA project was created by a group of students from the Department of Industrial Engineering, University of Padova, under the suggestion and guidance of personnel staff of the Center for Space Studies and Activities (CISAS) of the same University. The core motivation that brought together these students was the desire of researching new fields of application for drone technology. ARIA project has been carried on figuring this scenario: air quality monitoring.

2. ARIA: System Architecture

The selected system is a compromise between payload capacity, in-flight stability and manoeuvrability and low-cost. The system is based on a Tarot 650 Sport drone, for the platform; a Raspberry $Pi3b+$ for the controller devoted to sensor measurement; a suite of sensors for air quality monitoring (in particular NO, NO_2, CO and $VOCs$) based on Alphasesnse AFE board. The system is also measuring $PM_{2.5}$ and PM_{10} using the Nova SDS011 PM board. The ARIA Project is going to use simultaneously two drones and a fixed ground station, equipped with the same instrumentation in order two build a 3D map of the investigated area; for this first test flight only one drone has been used. There has been just some laboratory testing on the effect of the blade disturbances on the measurement [?] but a comprehensive study on sensor location on such platforms has not been done yet; therefore the ARIA project has designed a vertical boom were all the gas sensors are located. On the other hand, in the area above the UAV, there is a relatively constant air flow which drops significantly after a distance of approximately 40.0-50.0 cm for devices with characteristics similar to those used in the proposed solution. The airflow behaviour is similar aside from the UAV in the area with a radius from the center $r > 50.0\,cm$. To avoid the swirl area, it is recommended to place horizontal and vertical probes of the appropriate length. The use of horizontal probes often makes it difficult to achieve the conditions necessary for isokinetic sampling. In addition, it is necessary to use additional structures

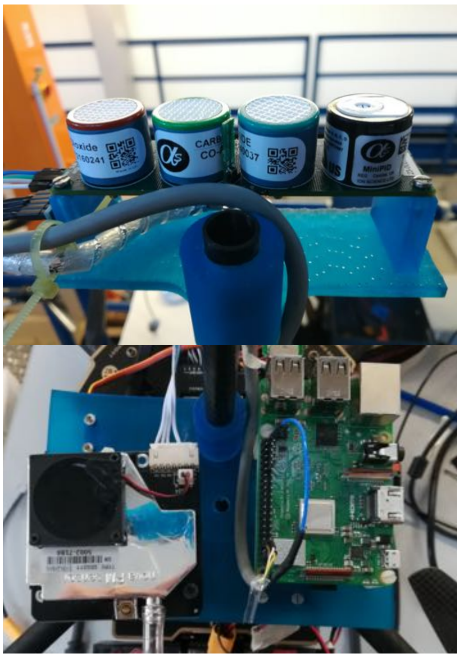

Figure 1. Top panel: the gas sensor equipment (NO, CO, NO_2 and $VOCs$ sensors; lower panel: PM Nova sensing system and Raspberry controller (on the right).

for their equalization. To overcome this problem, it was decided to use the vertical probe; the use of a boom in a vertical position does not affect the flight capabilities of the UAV since the entire system has a low center of mass, situated in the proximity of the battery.

Figure 1 shows an overview of the system, the gas measuring sensors, the particulate sensor and the Raspberry controller; while one of the two UAVs system is shown in Figure 2.

The UAV pilot or the UAV ground station operator (GSO) can communicate with the UAV wirelessly, using a radio controller (RC) transmitter or a computer, respectively.

The UAV drone is the Tarot 650 sport, equipped with the Pixhawk Cube Black controller board and the HERE2 GPS system; power is provided by a 6s Lipo battery able to give 10000mAh. Communication between the flight controller and ground station is via 433MHz telemetry link connected to a laptop; a 2.4GHz communication link is also ensured via a Taranis 9D+ Radio and an 8XR receiver onboard the UAV.

3. Sensor Payload

The sensor payload is composed by 3 subsystems:

1. Raspberry Pi 3b+
2. Analogue Front End (AFE) by Alphasense equipped with 3 gas sensors (NO, NO_2 and CO) and a PID (VOCs) sensor
3. Particulate sensor board for $PM_{2.5}$ and PM_{10}

A student bachelor thesis performed a FEM study on the sensors and the Pi3b+ support platforms. The elements have been studied in order to present a high resistance to vibrations and to allow the sensors and the boards to be housed in the most safest way. In addition, the study also sought to design very light components: the boards were built with a 3D PLA printer in order to host in a compact and reliable way all the instrumentation (see Figure 2).

3.1. Particulate sensors

The particulate sensor is a Nova SDS011 PM sensor able to measure $PM_{2.5}$ and PM_{10} concentrations with a resolution of $0.3\mu g/m^3$; range of measurement is: $0 - 1\,mg/m^3$ and the frequency

Figure 2. Tarot 650 Sport drone with the designed boom for gas sensor housing. The carbon fiber boom is approximately 50cm long and fixed to the supporting structure. In the forefront it is possible to observe the inlet tube for the PMs sensor. No variation in PM sensor was observed with or without the inlet tube.

of output is 1 *Hz*. The sensor is a COTS sensor used for house and environmental monitoring with consumption around 1 *W*. Tests on the sensor were performed in the lab and outputs were calibrated. The sensor is equipped with a 10 *cm* inlet pipe (see Figure 2) in order to facilitate the inflow of the air in the sensor. Sensor is linked to the Raspberry via a USB interface board allowing fast connection and is located on the drone main platform.

3.2. Gas sensors

The gas sensors have been positioned on a 50 *cm* boom in the center of the drone main platform and above the drone itself (see Figure 2) in order to reduce disturbances due to variable flux moved by the blades. Preliminary analysis show that the sensors are located in a non-altered flux allowing for reliable measurements. Due to possible disturbances from electromagnetic sources present on the drone (mainly telemetry antennas and electronics) a Faraday cage, not present in this study, but will be built around the gas sensors and tested in future flights.

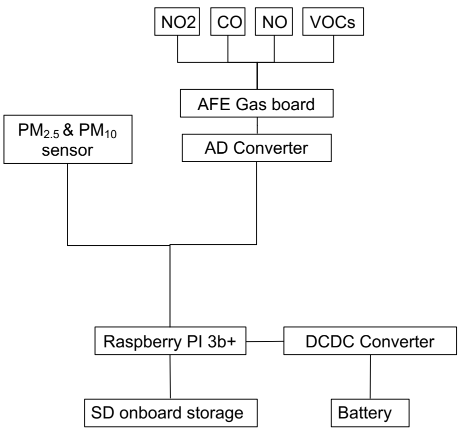

Figure 3. Sensors and Payload Architecture. Raspberry PI 3b+ is reading and saving on board all the collected data; an independent battery is giving power to the measuring system.

Figure 4. ARIA drone before flight on the field.

4. Flight test

The first test flight was performed in a semi-industrial area in the suburbs of Padova (Italy) during winter 2019 (see Figure 5); data were collected at 3 different heights, $5m$, $15m$ and $30m$.

A manual controlled test during daytime was performed and data were saved. A couple of sensors (in particular, NO and CO) experienced very high noise that was caused by the controller telemetry 433MHz antenna (in Figure 6 it is possible to identify the switch-ON of the telemetry link at second 360). This disturbance will be mitigated in future flights with an autonomous flight and no use of telemetry antennas. The particulate sensors were not affected by disturbances and a very interesting peak was observed in a specific time window during flight (around $1030\,s$ after launch) (see Figure 6) and is probably due to particulate coming from the nearby purification waterplant; the drone was at a stable altitude of $5m$ moving in an horizontal direction with velocities lower than $3\,m/s$ (Figure 5). Sensor outputs seem not to be sensible to velocity changes (both horizontally and vertically), confirming the fact that for low velocities the sensor are not affected by biases and that the integration time smoothes out the eventual disturbances (at least for the particulate sensors). In Figure 7(a) it is possible to see the 3D trajectory position of the entire flight; while in Figure 7(b) we have correlated the PMs values with the trajectory. The PM values at $15m$ and $30m$ heights are relatively low and similar. As it can be observed the peaks in PMs do not correspond to the highest or lowest trajectory path, but are located in a specific part of the flown area, corresponding to the last part at $5m$ height before the landing section. For this reason we think that the increase in PMs is mainly due to particulate that was brought by wind in the specific time of the measurement coming from the nearby waterplant.

5. Conclusions

With this preliminary test we demonstrated that drones can be used for monitoring 3D distribution of pollutants in urban and industrial areas. The selected quadricopter (Tarot 650) is small and can be easily equipped with instrumentation for the specific application; a manual or autonomous control can be foreseen. The measured data are not sensible to velocity changes if the velocity is relatively low. Some attention must be considered on the dependence of the sensor output to possible EMC interferences, since we observed that the 433MHz antenna signal disturbs some sensors; a possible solution could be a small Faraday cage around the specific sensible sensor head. A plan for future test with a swarm of drones is foreseen.

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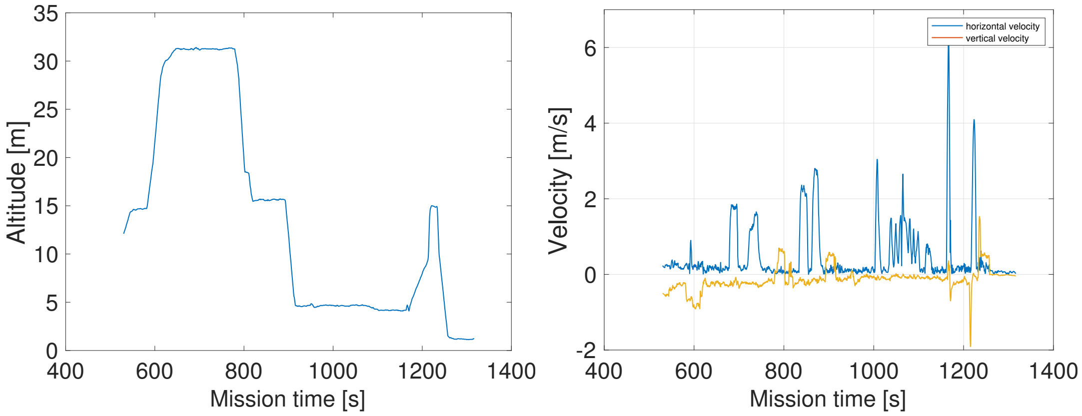
Conflicts of Interest: The authors declare no conflict of interest.



(a) Test mission altitude profile. First minute of data is not present due to the loss of connection with ground station in the first part after lift off. Data were collected at three different levels: $5m$, $15m$ and $30m$.

(b) Test mission velocity profile. Horizontal peaks are due to increase in horizontal position and are only positive; vertical peaks are due to increase or decrease of altitude.

Figure 5. Altitude and velocities during flight test.

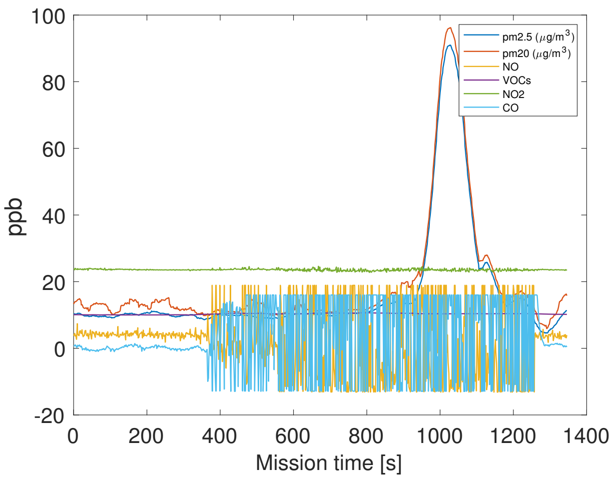
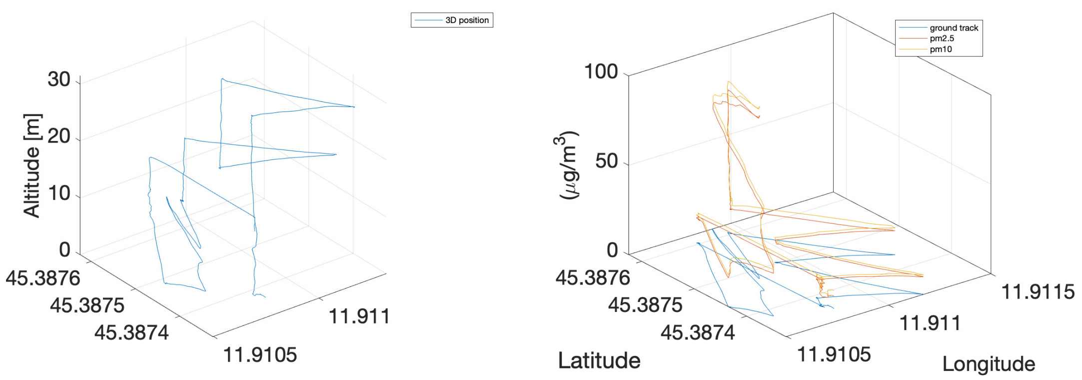


Figure 6. Gas and particulate concentrations. NO and CO sensors are noisy due to 433MHz antenna disturbances. Particulate peak value is probably due to particle present in a wind shear coming from the nearby waterplant.



(a) 3D trajectory of the performed suburban flight test.

(b) 3D $PM_{2.5}$ and PM_{10} measurement during flight w.r.t. trajectory. It can be observed that the highest PM values do not correspond neither to lowest or highest altitudes (see panel (a)).

Figure 7. 3D trajectory track and particulate measurement.