ARIA: Air Pollutants Monitoring Using UAVs

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***Abstract*—UAV technology, and specifically networks and swarms, have been an open research topic for many years. This is because of their potentially huge benefits at an affordable cost in a wide range of tasks. UAVs are commonly used in public and private fields. Their usefulness still comes with a price and some serious limitations, not completely surpassed yet. There are many proposals for protocols and algorithms trying to improve drone swarms but they are massively dependent on the actual scenarios and use cases. UAVs can fill a gap in modern Wireless Sensor Network, mostly because of their mobility and ability to fly at different heights. While drone swarms are prolific research topics, there is almost no interest investigating benefits of vertical deployment of this technology. It is proven that air pollution changes abruptly even at relatively short distances, both horizontally and vertically. We aim to provide a new tool to study air quality at different heights that even private citizens could afford. We will present an overview of ARIA project, a vertical drone swarm for air pollution monitoring. Considering the scope of our project, we will only utilize low-cost UAVs and sensors. Knowing the hard challenges inherent to UAVs and environmental monitoring, we're looking at preliminary results but we think this will become a valuable proof-of-concept for further research.**

***Index Terms*—UAVs; drone swarms; Wireless Sensor Network; low-cost ambient sensors; air pollution; environmental monitoring.**

I. Introduction

THE usage of Unmanned Aerial Vehicles (UAVs), also known as drones, was a particularly rich topic of research in the latest years. Due to the flexibility, mobility and affordable cost of drones, their usage can find countless applications even for private citizens. Considering the ever growing value of this technology, keeping track of the most recent scientific publications is vital. To provide better insight on a specific topic, this paper's main focus will be environmental monitoring activities. People are becoming increasingly aware of air pollution-related issues: current monitoring systems are not able to satisfy every need of modern cities and UAVs are valuable assets in this panorama. This paper aims to collect and explain issues of drone deployment for environmental monitoring activities. Drone swarms, gathering data through sensor-equipped UAVs and integrating them into current Wireless Sensor Networks will be addressed. The ultimate goal of this paper is outlining a preliminary proposal for ARIA project. Its purpose is the deployment of a vertical drone swarm to sense air pollution samples at different heights. The rest of this paper is organized as follows. Section II examines related works providing some preliminary insights. Section III describes environmental monitoring state-of-the-art. Section IV outlines our proposal for ARIA project. Section V summarizes the paper and presents the conclusions.

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II. Related works and state-of-the-art

A. Air pollution

Air pollution is extremely complex to evaluate. Pollution is mostly caused by human activities, so it is logical to measure it only in urban settings. There are six common pollutants consistently studied and analyzed as follows:

TABLE I
Major air pollutants [1]

Chemical symbol	*Substance*	*Characteristics*
CO	Carbon Monoxide	Colorless, odorless gas
NO_2	Nitrogen Dioxide	Highly reactive gas
O_3	Ozone	Pale blue gas
SO_2	Sulfur Dioxide	Colorless, irritating smell gas
$PM_{2.5}$ and PM_{10}	Particulate Matter	Inhalable particles
Pb	Lead	Metal particles

Sensor technology vastly improved in the last years. It started to be available not only to public environmental agen- cies, but also to people through low-cost sensors.

B. Low-cost sensors

EPA[1] is the acronym for Environmental Protection Agency (of United States). The Air Sensor Guidebook[2] offers every kind of information that amateurs (or even experts) need to know before adventuring into the complex world of air quality and low-cost sensors.

Conventional air pollution monitoring systems have low spacial and temporal resolution. Low spacial resolution means there are only few measuring elements deployed with small coverage. This is caused by the prohibitive cost of the devices. Low temporal resolution means the data analysis and dissemination is slow. This is due to the complexity and cost associated with the accuracy required. Conventional air pollution monitoring systems are suited for environment background monitoring. Low-cost sensors can be deployed more diffusely with high spacial and temporal resolution, trading most of their accuracy. They can be a great tool to measure personal exposure to air pollution. Their data should be evaluated critically: they are heavily influenced by many factors, especially temperature, humidity, wind and presence of other gases in the air. Usually the data gathered by low-cost sensors is available to public through the web. Due to their lightweight, only low-cost sensors can be mounted on drones: the aforementioned influence factors could introduce even more inaccuracy, especially wind generated from the rotors.

Yi Wei et al. present in [3] a long and detailed survey about air pollution monitoring, Wireless Sensor Networks and low-cost sensors. The paper describes common measurement targets and relative sensing techniques. Sensors are evaluated, classifying their performances by the most important parameters. The paper also explains Wireless Sensor Network categories addressing benefits and issues. Lastly, it assesses how drone technology could improve environmental monitoring systems.
In [4], the authors propose a Wireless Sensor Network that can monitor air pollution in a three-dimensional space (using only a single drone). The authors created two schemes addressing this scenario, with related algorithms. Sequential Monitoring Scheme, where the collection of pollution data is strictly sequential, and Dynamic Monitoring Scheme, where the collection is less frequent depending on the stability of a sub-area.

C. *Wireless Sensor Networks*

Wireless Sensor Network (WSN) purpose is collecting, analyzing, storing and publishing environmental data. A WSN can be placed into one of three types:

- Static Sensor Network (SSN);
- Community Sensor Network (CSN);
- Vehicle Sensor Network (VSN).

The sensors used in these networks could be both conventional or low-cost. Network type is unrelated to sensor type.

1) Improving WSNs with drones: Currently Wireless Sensor Networks are facing some particular challenges:

- lack of 3-dimensional sampling;
- switching behaviour;
- easiness of maintenance;

Current sensing devices are not easily and remotely programmable. Drones can be reconfigured at will, whenever the situation requires it.
The three current types of Wireless Sensor Network are static, move unpredictably or have some prioritary transport mission. Drones could be used specifically for environment missions and can smoothly be relocated to maintain locations.

D. *Drone systems*

Coordinating data collection and movements is quite hard, considering the low computational power of UAVs, the inaccuracy of GPS and the general wireless communication issues. Ref [5] is a survey on the communication issues releted to drone networks.
The energy constraint is really impactful on long missions and poses a major limitation to the spreading of drone technology.

Drones have excellent mobility and data gathering prowess, but cannot always rely on coming back to the base to deliver their information. Implementing reasonable communication protocols and algorithms is necessary to improve efficiency. Drone networks don't directly imply swarms: messages could be exchanged with base stations, antennas, any kind of UAV (not belonging to the swarm) and many others. Drone's control systems can be centralized or decentralized and always implement ad hoc networks. This comes as a consequence of the different nature of UAVs compared to classical networks devices and of wifi typical weaknesses (such as signal collision).

E. *Drone monitoring and sensing*

Drone monitoring and sensing capabilities are among the most valuable ones. Exploiting their mobility and flying movement, the target nodes can be reached in a timely manner. Drone monitoring is being exploited by many agencies since it is so versatile. Regarding urban settings, the environment chosen for this paper, UAVs can monitor noise, traffic, light, wind, temperature, humidity, air quality and many other parameters. To this goal, they need to be equipped with specific sensors. While some of them may be easy to transport (small weight and size, low cost, loose maintenance timing), many others (specifically air quality ones) may not be equipped so effortlessly. Drone monitoring progress will always be strictly correlated to drone networks and swarms progress. A single UAV is very limited in its performance due to its coverage, energy autonomy and small selection of sensors. Swarms can provide full coverage of an area, while coordinating the best routes to visit each sensing node. Equipping different drones with different sensors is far easier and more flexible than having one doing everything on its own. Quadcopters are the favourite platform[6][7][8][9] for monitoring and sensing due to their hovering ability.
A challenge emerged specifically from air quality sensor is the influence of the wind created by rotors movement. In [10] researchers addressed to this issue by studying the physical structure of the quadcopter, disclosing the best sensors placements. Unfortunately, this investigation needs to be carried out for each UAV model considered since their shape is quite diverse from each other. If the wind influence is too high on every side of the drone, it is required to build an extension (up to 20cm) that will stick out. Appropriate balancing is then also necessary.

III. ARIA PROJECT

A. *Overview*

ARIA project was created by a group of students from Department of Industrial Engineering, University of Padova, under the suggestion and guidance of the senior authors of this paper. The core motivation that brought together these students was the desire of researching new fields of application for drone technology. ARIA project's scenario is investigation about drones usage within air quality monitoring. Environmental pollution is becoming every day more threatening for our health and we wanted to develop a tool to monitor it in 3D. the project is funded by the Department of Industrial Engineering of our University.

B. Proposal presentation

ARIA project's ultimate goal is gathering data about the values of major pollutants in urban areas at various heights. Our tool will be a vertical drone swarm equipped with low-cost sensors and deployable by utilizing GPS coordinates. The information will be stored in a database, so that they can be post-processed and published whenever appropriate. The most interesting activity could be creating a contemporary vertical profile of pollutants concentrations for various time-periods. We've chosen to work with UAVs because after reading literature about environmental monitoring, we found omissions in Wireless Sensor Networks. The use of this new technology was already recommended thanks to its speed, mobility and capability to fly at different heights. The main constraint was the unavailability of low-cost and low bulk drones.

To differentiate ourselves from previous studies (since our knowledge would not be able to compete with them anyway) we wanted to explore vertical swarms. The study of pollution at different heights is not a popular topic and we wanted to investigate it.

The task for the multicopter will have a standard implementation: usually it will be a simple request to move towards some GPS coordinates, hover there while collecting samples and then return to the base whenever the time is up or the battery is too low. The flight will be planned before departure from a terminal. The vertical deployment doesn't need to be extremely precise, since sensor's accuracy is not sufficient for slight misplacements to matter. Since our approach will be careful and gradual, each entity belonging to the swarm will not communicate with the others. Considering this fact, we know the term ”swarm” is being used inappropriately. Wireless communication and real swarm implementation will follow as the project unfolds.

1) Drone model: The drone model will be a deciding factor for the success of ARIA project. Many of its physical parameters will influence sensing, maneuverability and battery consumption. Stability during air measurement is absolutely vital. Another feature is the programmability of the UAV, since we want to eventually deploy a vertical formation. Additionally, the more customization the drone offers, the more we can optimize movement, tracking and data gathering. Price can also be relevant since our budget is limited and we need to buy many other costly tools and pieces of equipment.

2) Sensors: In an urban setting the vast majority of pollutants is composed by the following:

- Carbon Monoxide (CO);
- Nitrogen Dioxide (NO_2);
- Ozone (O_3);
- Sulfur Dioxide (SO_2);

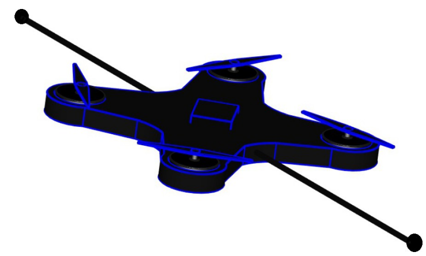

Fig. 1. Example of location of the sensors

- Particulate Matter ($PM_{2.5}$ and PM_{10});
- Lead (Pb).

Each of them can be measured by a low-cost sensor, but some measurement techniques are more prone to inaccuracy if mounted on a drone (due to stronger external factor influence). To limit this issue, the sensor will probably be installed on a protruding platform, that will be built considering UAV's stability.

To provide better accuracy in our data, we'll need to equip every drone with temperature and humidity sensors. Due to physical restrictions, only a single sensor for a major pollutant will be mounted (although some of them can measure multiple pollutants). To account for external interfering factors, sensing nodes location will be studied extensively before the deployment of the drones.

C. Current state

We organized three Work-Group (WG) that are developing the drone design:

1) Sensor's settings and choice, WG1: After reviewing the state of the art (and after asking researchers of the Chemical Department of the University), the WG1 is developing the measurement system (MS). It is composed by (see Fig. 2):

- Raspberry Pi 3
- Analogue Front End (AFE) by Alphasense
- A/D Front End by South Coast Science
- Gas sensors by Alphasense
- Particulate and Volatile Organic Compounds (VOCs) sensors by Alphasense

TABLE II
ARIA'S SENSORS

Substance	*Weight [g]*	*Range*	*Data sheet*
CO	< 6	500 ppm	[11]
NO	< 6	20 ppm	[12]
NO_2	< 6	20 ppm	[13]
VOCs	< 8	50 ppm (isobutylene)	[14]
PM	< 105	0.38 to 17 μm sph. eq. size	[15]

The AFE can handle four gas sensors plus the particulate sensor. Table II shows the configuration of our MS with a view of the sensors.

When the MS will be ready the WG1 is going to do ground and on-drone tests.

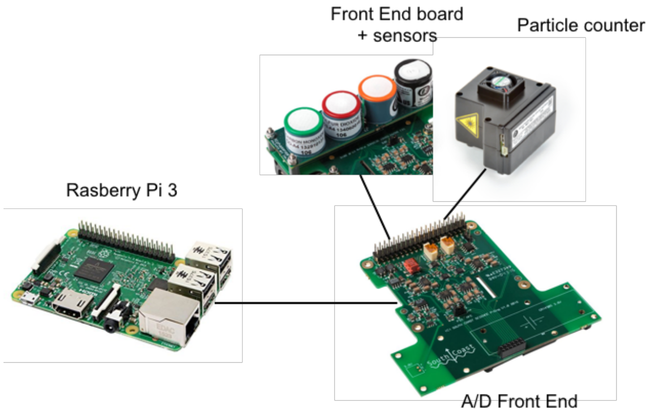

Fig. 2. Acquisition HW elements and connections.

2) Drone's design, WG2: From the data about weight, volume and electrical power of the MS the WG2 is developing the design of the ARIA drone. Two configurations are now under study: quadricopter or exacopter.
The main target of this group is the optimization of the drone's space used by the MS, it could be located on the upper or lower side of the plate. Due to the interaction between the airstream of the propellers and the sensor another useful location of the sensor could be outside the drone, as we can see in Figure 1.

The WG2 works also on the communication and control system using a Pixhawk as fly controller and the XBee platform as RadioFrequency comunication system.

For a start, we want to focus on building a single drone capable of collecting air samples, to an acceptable accuracy. This is the most challenging part of our research, because we need to analyse the performance of a large number of sensors to asses if they satisfy the requirements.

Fig. 3. Example of the airstreams near a propeller (image from www.simscale.com)

3) CFD model, WG3: This group works on the study of the airflow on the sensors, togheter with WG2 studies the possible location of the MS on the drone.

The measurements of the pollutant have to be done in the hoovering mode of the drone (static condition). Due to the propellers thrust, during the motion the airstreams become very complex and is hard to find a place where the sensors are not intrested by turbulence.

We have made some simulations about different configurations (quadricopter or esacopter) with different propeller's rpm (see Fig. 3).

To avoid airflow turbulence issues we are studying some unusual configuration, for example in Figure 1 we simulated an MS with sensors located on a balanced beam. The problem about this design is the link between sensors and the platform that can involve some losses of signal along the wires.

D. UAVs aligment in the swarm and sampling strategy

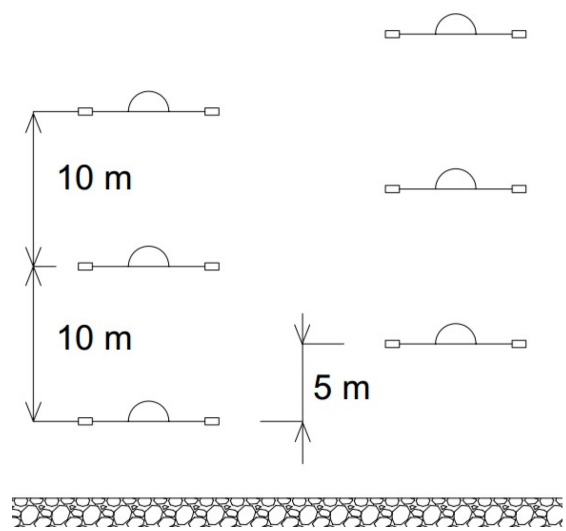

Fig. 4. UAVs aligment

Figure 4 shows our sampling strategy: UAVs are located on a vertical line with an offset of 10 m, as we said, previously, the measurements are done in a static condition.

After the sampling phase the formation will rise up 5 m, this operation will be done on a plane grid with a point every 50/100 m (the spacing depends by the environmental conformation). As GPS module we use a low cost receiver that allows us to use only the L1 signal so the stability of the position will be around 0.5 m. The quality of the GPS tracking depends also by the environment due to the presence of buildings, hills, trees and other structures.

With this strategy we obtain a vertical resolution of 5 m that allows us to get a detailed pollutant's vertical and horizontal profile.

E. Method of gathering data and pollution map creation

During the sampling, UAVs collect data about the environmental conditions (temperature, pressure and humidity), air pollutants and GPS track. We store all of this data on an On-Board storage control unit connected with the MS. At the moment, we have not planned a live data transmission between UAVs and the ground station, after each flight we download the results directly from the storage unit.

Integrating the positions with the vertical measurements will let the building of a 3D map of the air pollutants.

F. Future work

When the ARIA drone will be running, we are going to start the data collection phase. At first we are going to measure the air pollution level in the countryside near Padova (at the agricultural fields of the University of Padova located in Legnaro (PD)) and compare these results with measurements taken outside the university buildings in an urban environment. If we have the permissions, we want also to study the vertical profile of the air pollutants near roads and near industrial areas.

IV. CONCLUSION

An overview of the latest UAV technologies was carried out to evaluate their usefulness as air pollution monitoring systems. Wireless Sensor Network and low-cost sensors were discussed with specific reference to environmental monitoring. Finally, the ARIA project was presented by outlining its key features, introducing the future plans, goals and its challenges.This preliminary analysis points toward interesting potential uses of light drones for 3D environmental monitoring.

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