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DIPARTIMENTO DI INGEGNERIA DELL'INFORMAZIONE

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CORSO DI LAUREA IN INGEGNERIA INFORMATICA

SVILUPPO DEL SOFTWARE DI ACQUISIZIONE ED ELABORAZIONE DELLE MISURE DELL'INQUINAMENTO DELL'ARIA DI DRONI PROGETTO A.R.I.A.

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Abstract

In the recent years, awareness of the issue of Environmental Pollution has increased, and research shows that not enough has been done, until now, to reduce pollution. In this domain, the monitoring of air quality is fundamental to provide data which can be used to most effectively guide our efforts to reduce air pollution. At this time the monitoring of air quality is usually performed via stationary ground-mounted air pollution stations. However, research(??) has shown that air pollution can vary greatly at different heights, for this reason the *Air Pollutants Monitoring Using UAVs* (ARIA) project is aiming to develop a system to measure vertical gradients of air pollutants using vertical swarms of drones. The ARIA project solution is a low-cost monitoring system based on *Commercial off-the-shelf* (COTS) sensors and on multiple cheap drone platforms. The system is equipped with $PM_2.5$ and PM_10 sensors to monitor the particulate concentration and several other gas sensors (such as NO, NO_2, CO, etc.) and the use of *Unmanned Aerial Vehicles* (UAVs) allows to build a 3D map of pollutants in a specific area. This could prove very useful around buildings in urban areas and possibile polluting plants in industrial areas. In this thesis are presented the system platform, the software implementation and a test flight.

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List of abbreviations

ARIA *Air Pollutants Monitoring Using UAVs.*

COTS *Commercial off-the-shelf.*

EPA Environmnetal Protection Agengy.

UAVs *Unmanned Aerial Vehicles.*

WSN *Wireless Sensor Network.*

Chapter 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. 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 [1][2]. 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. Furthermore, these approaches don't account for the vertical gradients of air pollution levels. As shown in research [2][1] the concentrations of air pollutants can vary greatly at different heights and this is a sensitive factor in circumstances such as buildings in urban areas and possible polluting plants in industrial areas. The usage of Unmanned Aerial Vehicles (UAVs) has been particularly rich in the latest years due to their flexibility, mobility and affordable cost. 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, 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 UAVs, which we are deploying in vertical swarms, to measure pollution levels at different heights. 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 [3] 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.

1.1 Related works and state of the art

1.1.1 Air Pollution

According to [4] "Air pollution can be defined as the presence of toxic chemicals or compounds (including those of biological origin) in the air, at levels that pose a health risk. In an even broader sense, air pollution means the presence of chemicals or compounds in the air which are usually not present and which lower the quality of the air or cause detrimental changes to the quality of life (such as the damaging of the ozone layer or causing global warming)". Air pollution is extremely complex to evaluate and there are many polluting substances in the atmosphere. The Environmnetal Protection Agengy (EPA) (of United States) takes these 6 (the "criteria air pollutants") in consideration in its studies:

Table 1.1: Criteria air pollutants and their health effects [5]

Chemical symbol	Substance	Characteristics	Effect
CO	Carobon Monoxide	Colorless, odorless gas	Reducing oxygen delivery to the body's orogans and tissues
NO_2	Nitrogen Dioxide	Highly reactive gas	Risk of emphysema, asthma and bronchitis diseases
O_3	Ozone	Pale blue gas	Chest pain, coughing, throat irritation
SO_2	Sulfur Dioxide	Colorless, irritating smell gas	Risks of bronchoconstriction and increase of asthma symptoms
$PM_{2.5}$ and PM_{10}	Particulate Matter	Inhalable particles	Premature death and respiratory symptoms
Pb	Lead	Metal particles	Accumulate in bones and affecting the nervous system

1.1.2 Air quality monitoring

Air quality monitoring is an essential part in order to know what measures to put in place [6] to protect our health and the environment, which are strongly connected. In the Veneto region, Italy, the area of this study, the ARPAV[7] has put in place a conventional monitoring network to track major air pollutants and enforce restrictory measures on polluting factors (such as transportation) if necessary. Figure 1.1 shows the map of ARPAV's current 2D monitoring network, which gives an example of the very low spacial resolution of conventional air quality monitoring systems.

1.1.3 Low-cost sensors

The EPA also provides the Air Sensor Guidebook[8] which gives extensive information on air quality and low-cost sensors. Due to their prohibitive cost and complexity, conventional air pollution monitoring systems have low spacial and temporal resolution. Low-cost sensors, instead, can be deployed more diffusely with high spacial and temporal resolution, while trading most of their accuracy. They are, in fact, heavily influenced by many

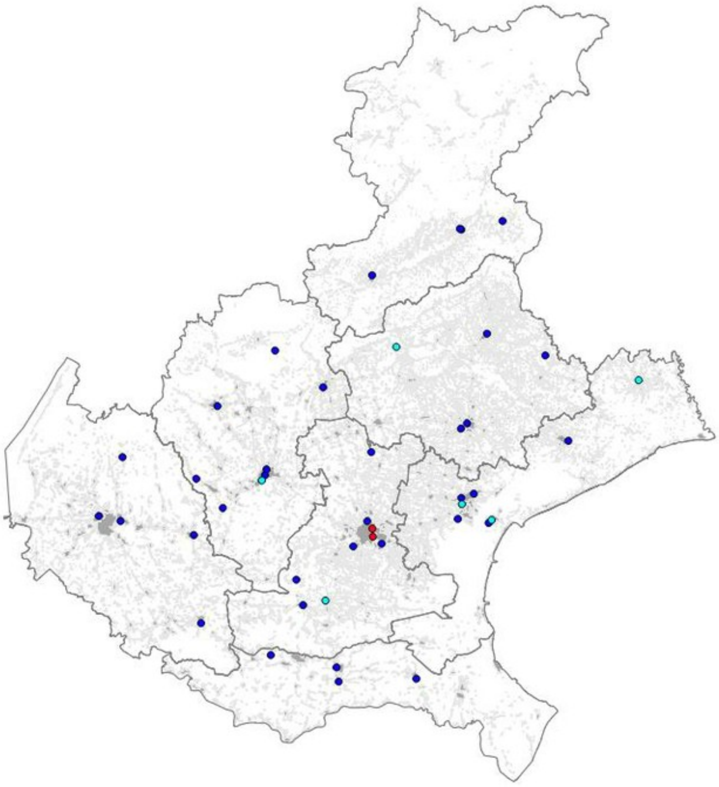

Figure 1.1: ARPAV monitoring netowrk in the Veneto region, Italy[7]

factors, especially temperature, humidity, wind and presence of other gases in the air. 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. [9] among other things presents an evaluation of air quality sensors classifying their performances by the most important parameters.

1.1.4 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.

1.1.5 Drone monitoring and sensing

Thanks to their mobility and flying movement, drone monitoring and sensing capabiliteis are very valuable. In urban settings UAVs can monitor noise, traffic, light, wind, temperature, humidity, air quality and many other parameters. As shown earlier, conventional air quality monitoring systems have very low spatial and temporal resolution. UAVs based systems could measure specific areas with great convenience and felxibility and hybrid ground and air based solutions could routinely track the air pollution levels of parts of a city. A single UAV, however, is very limited in its performance due to its coverage, energy autonomy and small selection of sensors. Swarms, instead, 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. [5], [10], [11], [12] propose different solutions for a *Wireless Sensor Network* (WSN) using UAVs. [11] in particular examines an application in smart cities, where a hybrid ground and air based system tracks an urban area.

1.2 Dissertation structure

This dissertation describes the ARIA project solution for the monitoring of air pollution. It is divided into 6 chapters:

- Chapter 1 describes the introduction, an overview on the topic of air pollution, the motivation to approach the problem, the motivation of the proposed solution, related works, the state of the art and the dissertation objective.
- Chapter 2 describes the system architecture, that is the UAVs that are being used, their design, specifications and functionality.
- Chapter 3 describes the sensor payload, the motivation of the adopted sensors and their use.
- Chapter 4 describes the software implementation for the data collection of the sensors and the communication of the UAVs.
- Chapter 5 shows the results of a test flight using the proposed solution.
- Chapter 6 presents what conclusions can be taken after all the developed work, and what improvements can be done in the future.

1.3 Dissertation objective

The objective of this dissertation is to describe the solution proposed by the ARIA project for air pollution monitoring, in particular the software impelementation, to show preliminary results and discuss their revelance in future applications.

Chapter 2

ARIA project

2.1 Overview

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'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.

2.2 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.

Chapter 3

ARIA: System architecture

The selected system is a compromise between payload capacity, in-flight stability and manoeuvrability and low-cost. The system is composed by:

- Tarot 650 Sport drone, for the platform
- Pixhawk Cube Black controller board
- HERE2 GPS system
- Raspberry Pi3b+ for the controller devoted to sensor measurement
- a suite of sensors for air quality monitoring (in particular NO, NO2, CO and VOCs) based on Alphasesnse AFE board
- Nova SDS011 PM board to measure PM2.5 and PM10
- Taranis 9D+ Radio and an 8XR receiver

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. There has been just some laboratory testing on the effect of the blade disturbances on the measurement [3] 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 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 3.1 shows an overview of the various system components; while Figure xxx shows various details of one of the drones. 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. Power is provided by a 6s Lipo battery able to give 10000mAh. Communication between the flight

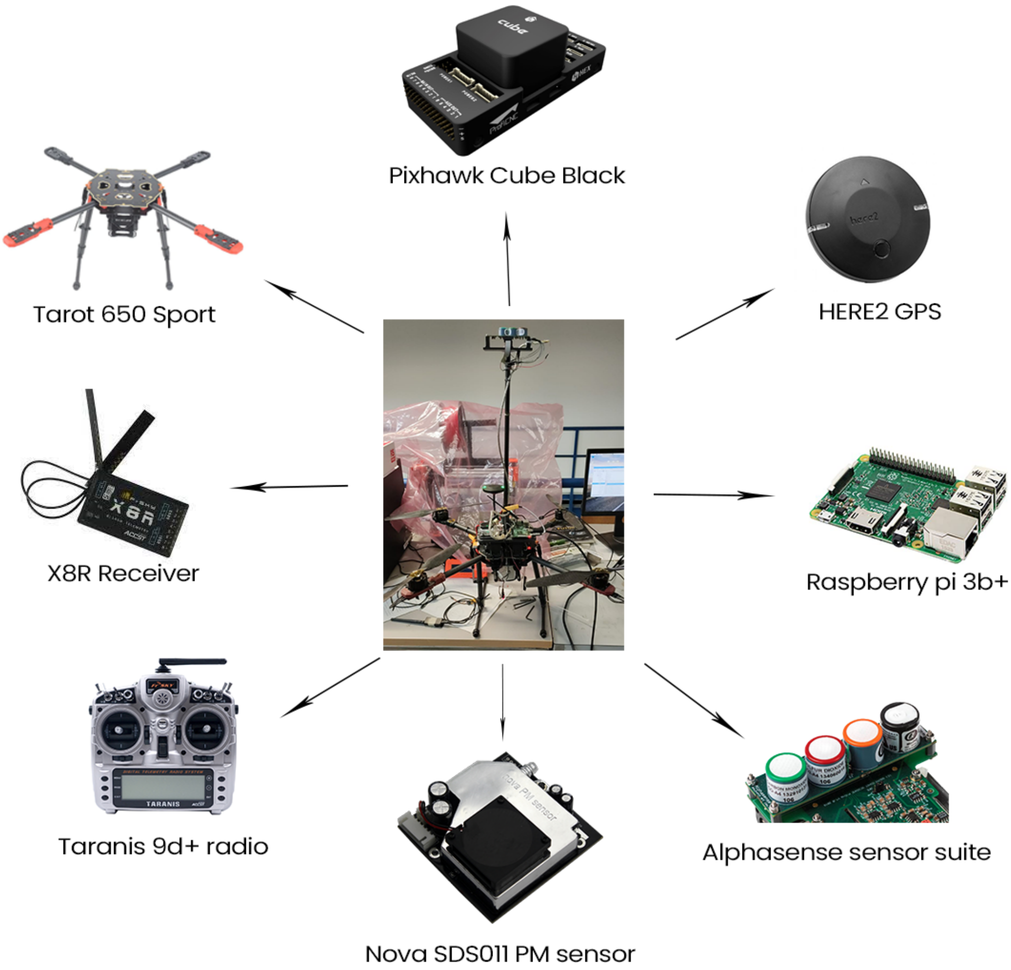

Figure 3.1: ARIA drone system architecture[7]

controller and ground station is via 433MHz telemetry link connected to a laptop; a 2.4GHz communication link is also ensured via the Taranis 9D+ Radio and an 8XR receiver onboard the UAV.

Chapter 4

Sensor Payload

Chapter 5

ARIA: Software implementation

Chapter 6

ARIA: Test flight

Chapter 7

Conclusions and future work

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