Real-time urban air pollution monitoring using unmanned aerial vehicles

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***Abstract**: Measuring pollutant gases for real-time air quality monitoring is a challenging task that claims a lot of time of observation and large numbers of sensors [1]. Unmanned Aerial Vehicles (UAVs) equipped with different micro-sensors have been introduced for air quality monitoring, as they can offer new approaches and research opportunities in air pollution and emission monitoring instead of ground-based monitoring systems [2]. UAVs with mobile monitoring devices are an effective, flexible and alternative mean to collect air pollutant concentration data [3]. Hence, deployment of a fleet of UAVs could be considered as an acceptable alternative for the purpose of air monitoring [4]. The aim of this paper is to elaborate performance capabilities of UAVs for effective monitoring of air pollution, providing the ability to measure air pollutants with high sensitivities.*

***KEYWORDS**: UNMANNED AERIAL VEHICLES, AIR POLLUTION, MONITORING*

1. Introduction

Air pollution has been identified as a leading risk factor for the global disease burden [5]. In response, air monitoring networks have been established to monitor concentrations of air pollutants in the ambient air.

Air pollution monitoring has recently become an issue of utmost importance in the society. Environmental organizations and governmental institutions are beginning to consider the monitoring of environmental pollutants as a primary goal [4].

Measuring air quality is important to make sure that the general public, governmental agencies and any involved party is conscious of the state of pollution, and to trigger taking the required precautions to ensure the safety of the population [1].

However, the current monitoring networks are often considered insufficient to cover large areas or implement effective pollution control strategies [5].

As the Unmanned Aerial Vehicles (UAVs) technology has gained popularity over the years, it has been introduced for air quality monitoring [3].

Spatial and temporal resolution of data from ground, manned aircraft and satellite measurements is relatively low and often inadequate for local and regional applications [2]. In addition, satellite and airborne sensors can be costly, restricting the use of these platforms to sporadic tests rather than routine analysis. Furthermore, taking measurements close to pollutant sources may not always be possible and it could be too dangerous or risky for manned aircraft to fly close to the ground [2].

All these reasons encourage the use of small, lightweight UAVs for a wide range of applications, including atmospheric measurements [6].

UAVs have the potential to be used for an enormous range of applications, many of which involve urban settings. A wide range of sensors, improvements in data post-processing, and continuing evolution of the drones themselves are expanding the potential uses [7].

UAVs can help to environmental researchers in the field of air quality monitoring. Hence, this paper elaborates the potential of UAVs for air quality monitoring, together with their advantages/disadvantages characteristics. Also, classification of UAVs is presented, which is important for analysis of their performance capabilities.

2. Introduction to Unmanned Aerial Vehicles (UAVs)

Assessment of air quality has been traditionally conducted by ground based monitoring, and more recently by manned aircrafts and satellites. However, performing fast, comprehensive data collection near pollution sources is not always feasible due to the complexity of sites, moving sources or physical barriers [2].

Additionally, satellite and sensors can be costly resulting to restrictions in the analysis. These limitations together suggest the use of small, lightweight UAVs for atmospheric measurements and monitoring [3].

Recently, Unmanned Aerial Vehicles (UAVs) have become a cheap alternative to sense pollution values in a certain area due to their flexibility and ability to carry small sensing units [8].

Unmanned Aerial Vehicles (UAVs) are an aircraft without a pilot. Furthermore, these vehicles are remotely controlled, semiautonomous, autonomous, or have a combination of these capabilities. In a technological context, a drone is an unmanned aircraft, like a flying robot. The aircrafts may be remotely controlled or can fly autonomously through software controlled flight plans in their embedded systems working in conjunction with onboard sensors and GPS [6].

A UAVs system typically consists of the UAV itself, a ground station, and a few onboard gadgets, such as a first-person view camera [5]. In many applications, UAVs are simply used as a carrying platform and do not intervene with the operations of the onboard gadgets. The controls of the UAVs and the gadgets are often separated as well. For air quality monitoring, however, the UAVs must function beyond a simple platform that carries multiple air pollutant sensors. It is more important for the UAVs to integrate the data from all onboard sensors and tag the data with geo-location information in real time [5].

These small, lightweight UAVs can provide more accurate information on air pollutant vertical distribution throughout the atmosphere, which is needed to understand air quality and composition in specific atmospheric layers [3]. They are being used in various air quality control methods for measuring particulate matter and VOCs as well as measurements relating to meteorology such as temperature, humidity, pressure and winds.

In addition, UAVs are quickly deployable, cover large areas and can monitor remote, dangerous or inaccessible locations, increasing operational flexibility and resolution over land-based methods [6].

Therefore, UAVs may be a viable option for air quality data collection [2].

3. Classification of UAVs

As the use of drones for civil purposes is relatively new, there is no much of legislation existing yet [6]. However, in order to define legislation, a classification is needed previously to determine the different needs and requests.

There are two types of UAVs in existence that can help in determining air quality: fixed wing and rotary wing [1]. Fixed wing UAVs are comparative in configuration to planes used in human and cargo transportation. On the other hand, rotary wing UAVs are much similar to manned helicopters and are excellent for tasks that require the UAVs to stay still in one place or to move in a limited area [1].

Fixed wing UAVs can carry larger payloads, but must remain in an X-Y plane with constant motion. Rotary wing UAVs can only carry small payloads, but has the capability of collecting samples while it is in motion and also when it is hovering over a specific location [3]. UAV can be used successfully for this type of work because they are light in weight and can fly from one place to another relatively easily.

Table 1 below gives an overview about the differences between fixed wing and rotary wing UAVs in terms of their advantages and disadvantages.

***Table 1:** Comparison between fixed wing and rotary wing UAVs*

	Fixed Wing	Rotary Wing
Advantages	- High speed - Long distance traveling - Heavy payload - Smooth gliding through air (sleek structure) - Minimal maintenance process	- Multi directional (can hover) - No need for runway to takeoff or land
Disadvantages	- One directional (cannot hover) - Runway or launcher is needed to takeoff and landing - Commercial use is restricted by rules and regulations	- Complex design - Low operational time - High cost - Very light payload

Source: [1]

UAVs encompass a wide range of different platforms which, due to their physical size and power, differ in terms of their capability and simplicity of operation. These factors impact the payload carrying capacity, speed, altitude and range of flight, which determines the different applications that can be performed by each type of UAVs [2]. Figure 1 shows examples of fixed and rotary wing UAVs. The nomenclature adopted for civil and scientific use has generally followed the existing military descriptions of size, flight endurance and capabilities.

***Figure 1**: Example of a small fixed wing (a) CyberEye II; (b) Silverton Flamingo; (c) SenseFly Swinglet and rotary wing (d) AcsTec Pelican; (e) DJI F550; (f) DJI S800 unmanned aircraft (All the UAVs shown are part of the fleet of the Australian Research Centre for Aerospace Automation).*

Source**:** [2]

Table 2 presents another classification of UAVs taking weight as criteria.

***Table 2**: Different types of UAVs on the basis of weight*

Type of drone	Current and potential future uses	Current regulation
Small (<20/25kg) Price 140-28000€	Leisure and commercial use (e.g. surveillance, inspection, photography)	Falls under Member State regulations
Light (20/25-150kg) Price 55000-420000€	Used in geospatial surveying and wide-area surveillance. Potential to inspect pipelines and power cables, spray crops, search and rescue, control borders and monitor forest fires	Falls under Member State regulations
Large (>150kg) Price 670000€ and above	Used by the military and defense forces. Potential to carry cargo and passengers	Civil drones with an operating mass of more than 150 kg fall under Regulation 216/2008/EC and EASA competency, unless operated by a state agency

Source: [6]

UAVs can offer high resolution spatio-temporal sampling, which is not possible or feasible with manned aircraft [2]. Some UAVs systems are more flexible than others, with the ability to carry multiple sensors and operate in different flight modes (hybrid rotary/fixed wing designs).

Questions still need to be addressed regarding the miniaturization of sensors, which seems to be the main issue when working with lightweight UAVs [2]. In fact, the diverse range of UAVs payload capacity is primarily made by the difference between rotary and fixed wing UAVs.

4. *Performance and capabilities of UAVs*

UAVs are operationally more versatile and visible compared to land-based approaches or other aerial methods, such as manned aircraft and satellites. Conducting atmospheric measurements in remote locations is one situation where the use of small, lightweight UAVs is of particular benefit. In fact, the reduced size, weight and power needs of these flying robots, along with the reduced cost of the platforms and instrumentation, make them highly suitable for these operations [2].

UAVs or drones can carry a wide range of sensors with an equally wide range of applications to aerial points that were previously expensive, or impossible, to reach [7]. Depending on the sensors used, multiple data sets may be collected with a high spatial and temporal resolution [2].

Potential applications include [7]:

- Sampling air quality over a broad area in a short period of time, using a fixed-wing drone: this application would dramatically improve air quality information but at a significant risk to safety.
- Sampling pollution point sources, such as an industrial or a construction site: research is required to determine the reliability of air samples taken by drone from above a site, compared to those taken at or near-ground; this may lead to greater compliance of industry to environmental regulations.
- Sampling vertically, using a rotary wing drone at a single GPS location: this may help to predict near-future changes in ground-level pollution, particularly of particulate matter.
- Research: improve our understanding of the movement of pollutants during specific meteorological and temporal conditions.

5. *Pros and cons to UAVs and current challenges*

For every new technology to be accepted as a research tool, showing the advantages is most important. In addition, disadvantages could become a driving force for the future research. This also applies to the technology of UAVs.

Table 3 presents advantages and disadvantages if the process of usage of UAVs as a small robotic platforms for air quality research.

The advantages of a UAVs must outweigh the disadvantages and also be competitive with ground-based methods. If UAVs are adopted on a wide scale and if their advantages are studied and proved, than the balance between advantages and disadvantages could be found.

This emerging unmanned aircraft technology faces challenges that somehow slow down the development. The increase in drone use which recently gains popularity raises privacy concerns and even the word “drone” has a real negative first impression [3].

***Table 3**: Overall advantages and disadvantages for the use of UAVs in the atmospheric research domain*

Advantages	**Disadvantages**
flexibility: available wide range of UAVs applications	payload, speed, power and endurance limitations at small, low-cost UAVs
safety: no risk for crew in dangerous environments (chemical, biological or radiological hazards)	safety: risk of aerial collisions with piloted aircrafts, wildlife, and inanimate objects and collisions to ground level [7]
time and cost savings: especially with small UAVs platforms	security, including privacy [7]
repeatability: the same programmed flight could be followed every time by ground station	flight issues: interference with other instruments (vibration effect) [3]
data collection: small UAVs can take measurements at any point in three dimensional space	sensors limitations: availability of professional sensors and sensor integration into a network
easy to deploy – no need for airport runways	sensor size limitations: smaller sensors may have less sensitivity
national regulation in many countries for the use of UAVs [3]	aerospace regulation: operating regulations of UAVs aren't globally defined

Source: according to [2]

***Table 4:** Challenges in UAVs-based air monitoring platform*

Low-cost UAVs. Proprietary professional UAV platforms are expensive and require specialized design and maintenance; also do not allow the general users to customize their needs.
Synchronization of monitoring sensor data and GPS data. For real-time monitoring and geospatial data modeling, air pollutant data and GPS data need to be synchronized, as they come from two separate components.
Multiple air pollutants. Both the scientific community and regulatory agencies have been shifting from the traditional single-pollutant approach toward a multi-pollutant approach to quantify the health consequences of air pollution mixtures. This trend requires a platform that can integrate multiple sensors with different operating principles.
Energy efficiency and flight time. A typical UAVs in the price range of $500 to $2000 can fly for about 15 to 30 min on one fully charged battery. Carrying additional devices may reduce the UAVs flight time, as the onboard devices add weights to the UAVs and the devices themselves consume electricity. A typical USB-powered micro-controller device consumes power in the range of 1 W to 10 W. It is necessary to study and find a design with hardware and software to reduce the weight and energy consumption of the UAVs system.
Safety and restrictions in cities. UAV's flight paths need safe airspace to avoid many obstacles in a city environment, such as buildings, lights, power distribution lines, trees, no-fly zones and so on. Also, UAVs cannot be deployed without restrictions. Under current aviation safety operating regulations, restrictions are placed on their use in commercial, research, and private applications.

Source: [5]

However, the challenges are not simply technological, in fact, policy and regulations, which differ between countries, represent the greatest challenge to facilitating the wider use of UAVs in atmospheric research [2].

However, with more complexity and capability comes more maintenance, and additional specialist skills may be required. Larger platforms are costly and require a significant financial investment. Perhaps, the most important consideration is the safety of using such platforms in commercial applications, since they have the potential to cause considerable damage (to humans and property) and as such, fall under stricter operating guidelines than smaller UAVs [2].

6. Conclusion

To quantify the effects of atmospheric pollution on human health and environment, detailed information on the characteristics of pollutant concentration is needed. However, data from ground bases and satellite measurements are relatively low and often inadequate [3].

In recent years, to deal with the aggravation air pollution, the Unmanned Aerial Vehicles (UAVs) have been widely used to monitor the pollutant air. The UAVs monitoring system is expected to be an effective emergency tool for monitoring air pollutant thanks to its high resolution, flexibility, quick response, subjectivity, accuracy and impregnability of the terrain [9].

The Unmanned Aerial Vehicles are becoming an attractive experimental platform for high-spatial-resolution, near-surface vertical profiling of atmospheric pollution in recent years [5]. Recent advancements in UAVs technology present a low-cost solution for sampling the lower troposphere, taking advantage of their abilities to maneuver in both the horizontal and vertical dimensions and to hold a fixed position in the air even under high-wind conditions [5].

Hence, this paper outlines the main capabilities of UAVs, together with their classification and performance applications.

The future of UAVs for use in air quality applications is promising, thanks to the capability and flexibility of robotic platforms [2].

Promising characteristics of UAVs are long flight duration, improved mission safety, flight repeatability due to improving autopilots, and reduced operational costs when compared to manned aircrafts [3].

7. Literature

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