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UAVs Based PM Pollution Monitoring

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Abstract – **Technologies using Unmanned Aerial Vehicles (UAVs) have been the subject of research for many years now. They are increasingly used in a number of public and private projects. UAVs with their mobility and ability to fly at different altitudes can compensate for some shortcomings in the wireless sensor network and offer an alternative approach to data harvesting. With their help, it is easy to allow spatial research of different areas/spaces. This is particularly important in the study of air pollution, which changes sharply even over relatively short distances in the horizontal and vertical directions.**

In the present study is presented a research of possibilities for application of a new instrument for studying the air quality at different altitudes, which is accessible to a wide range of users. The approach is based on using cheap UAVs and low-cost air quality sensors. This paper shows the relevance of a customized, off the shelf UAV equipped with mobile monitoring devices as an effective, versatile, and unconventional means to collect three-dimensional air pollutant concentration data.

Keywords – **air quality, environmental monitoring, unmanned aerial vehicle (UAV), particulate matter (PM) concentration.**

I. Introduction

The present study aims to explore problems of the implementation of the UAV for environmental monitoring activities.

Main tasks to achieve the goal are

- Collecting data by sensor-equipped UAVs and integrating them into wireless sensing networks
- Air pollution data collecting at different altitudes.

Currently, wireless sensing networks face some specific challenges:

- Limitations on spatial sampling
- Maintenance difficulties
- Unstable behaviors in network modifications.

Current sensor networks do not always provide easy and remote reprogramming capabilities while the drones can be easily reconfigured as needed.

Systems for data collecting using drones

Coordination of data collection and movement is quite difficult, given the low computing power of most UAVs, GPS inaccuracy and standard wireless communication issues. Restrictions on power supply are crucial for the duration of missions and are the most serious obstacle to the propagation of data gathering technologies using drones.

UAVs have excellent mobility and ability to collect data, but they cannot always rely on returning to the base to transfer their information. The application of reasonable communication protocols and algorithms is necessary to improve their efficiency.

Messages can be exchanged with base stations and other unmanned aerial vehicles. Drones management systems can be centralized or decentralized but always use ad hoc networks ("computer to computer"). This is a consequence of the different nature of unmanned aircraft and the high levels of security required when compared to classic network devices (typical of Wi-Fi weaknesses - collisions) [1].

Using their mobility and hovering, monitoring points can be reached in a timely manner and with high precision. Monitoring through drones is used by government agencies because of their high flexibility.

In terms of urban conditions, which are the main subject of the present study, UAVs can be used to measure environmental parameters such as noise, illumination, wind speed, temperature, humidity, air quality and much more. For this purpose, they must be equipped with specific sensors. While some of them can be transported easily (low weight and size, low cost, easy maintenance), many others (especially air quality) require a serious investment.

Quadcopters are the preferred platform for monitoring because of their ability to maintain a static position for long periods of time (hovering). In them, a serious challenge, especially for air quality sensors, is the influence of air jets created by the rotor rotation. The problem of choosing the best location of the sensors is examined in [2] based on the physical structure of the quadcopter. Unfortunately, such research should be done for each UAV model, as their shape is quite different. A commonly used approach is the use of extensions to suck the air away of the main air jets.

A sensor module based on the use of multi-rotor UAVs and a sampling probe was developed. An important design goal is to ensure the possibility of emission research from a point source. In the following sections are described these experiments and are examined their results.

The main purpose of this work is to develop and test cost-effective and efficient environmental monitoring solutions using Wireless Sensor Networks (WSN) and drones, based on the latest technology advances.

II. Materials and Methods

A. Sensor integration

The PM concentration measurement module is based on the Alphasense (Great Notley, Essex, UK) OPC-N3

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particle counter and a microcontroller [2]. In addition to the particle counter, the module is integrated with:

- ESP32 microcontroller module with built-in Wi-Fi communication
- OPC-N3 - particle sensor
- Bosch integrated BME680 sensor including barometer, temperature sensor, humidity and air quality sensor
- GPS module - uBlox LEA6
- Wind velocity sensor based on Pitot tube and differential pressure sensor MPXV7002DP
- Rechargeable battery 2.5 Ah (3.7 V).

The architecture of the particulate matter monitoring module is presented in Fig. 1.

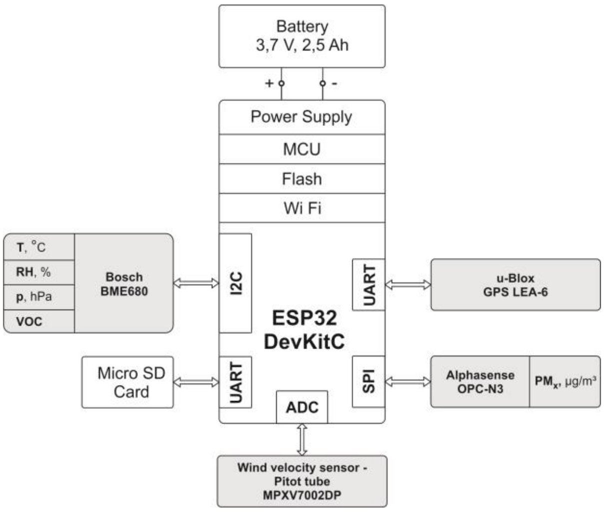


Fig. 1. Architecture of sensor module

The information from each sensor (e.g. particulate matter, pressure, temperature and humidity) is sent to a ground station via a Wi-Fi wireless connection for monitoring and recording and besides it is saved on a micro SD card used by ESP32. The particulate matter monitoring module is programmed to have time for reaction of 0.2 s. Time synchronization is achieved mainly by using a GPS time stamp for each reading.

The name of each log file is also recorded with the time and date synchronized at the exact time of the GPS module.

The total weight of the test module is 350 gr and has the following dimensions: 14.0 cm x 9.0 cm x 10.0 cm.

B. Multi-rotor UAV

The small multi-rotor UAV used for the study is Mavic Pro, from the company DJI, allowing flight duration with a load of 350 gr approximately 15 minutes. The multi-rotor UAV Mavic Pro is the chosen flying platform thanks to its good stability, ease of handling, flexibility and the options it offers for modifications and service. The UAV is modified to carry an air sampling probe and a box in which the sensor module is mounted as shown in Fig. 2. When using multi-rotor UAVs, two major problems are identified when taking a representative sample of air from the atmosphere:

- Difficulty in identifying areas around UAVs in which airflow can be considered as isokinetic and
- Designing a suitable air sampling probe and determining its most favorable location on UAV.

Fig. 2. Quadcopter and integrated gas-sensor system with a probe.

To understand the interference produced by the propellers in the volume of air to be explored, a complex experiment is required for each particular UAV. Through this experiment, it is possible to observe the air volume behavior around the multi-rotor UAV and to determine if and in which areas around it an isokinetic flow is possible.

An example of such a study, presented in [3], of a multi-rotor UAV is shown in Fig. 3.

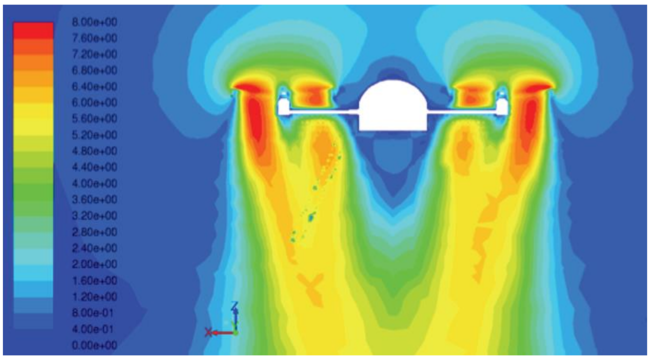


Fig. 3. Influence of rotation of the drone blades on the air movement around the UAV

Isokinetic flow is an important factor in the observation or sampling, especially for particles with a diameter less than 10 µm, otherwise the values obtained may be accompanied by significant errors.

In the presented research it is not envisaged conducting experiments to monitor the air volume behavior around the multi-rotor UAV. A literary study of solutions proposed for UAVs with similar basic technical characteristics and number of rotors [4, 5] has been made.

In a number of studies, through experimental observations and simulations, it has been found that the vortices induced by the multi-rotor UAV are very uneven in the area below it. Free turbulence arises, which is due to the collision of air layers moving at different velocities [6, 7, 8]. On the other hand, in the area above UAV, there is a relatively constant air flow which drops significantly after a distance of approximately 40.0-50.0 cm for devices with close characteristics as used in the proposed solution. The airflow behavior is similar aside from the UAV in the area with a radius from the center above 40.0-50.0 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 proposed solution was chosen as the most suitable solution for the PM system, using a vertical probe mounted 50 cm from the center of the UAV (Fig. 2). An additional advantage of the vertical probe is that it has a constant exposure to air sampling regardless of the orientation of the multi-rotor UAV or the wind.

III. Experimental Results

A. Data Acquisition

Data acquisition was conducted in an urban area, at Technical University (TU) campus in Sofia. For more examples of different sampling sites look at [9] .

The PM sensor data was recorded in μg/m^3. Relative humidity, pressure and temperature were acquired from the sensor. Height was derived from the GPS module while the wind speeds from the Pitot tube. Data logging was done through a phone application. For the position of the UAV, the position coordinates and elevation of each data point were derived from the UAV GPS data logger.

B. Vertical distribution of PM concentration

This study also aims to determine the vertical distribution of particulate matter using integrated semiprofessional PM sensor and UAV. The field experiment was conducted on 10 May 2019 covering several flights.

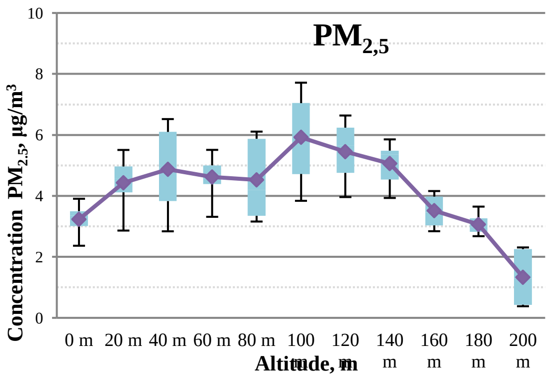


Fig. 4. Boxplot of PM$_{2.5}$ concentration changes on 10.5.2019 with altitude increase of 20 m in intervals with a hovering of 40 secs

Generally, the PM concentration increases as the altitude increases and from around 100 m to 200 m the concentration decreases (Fig. 4).

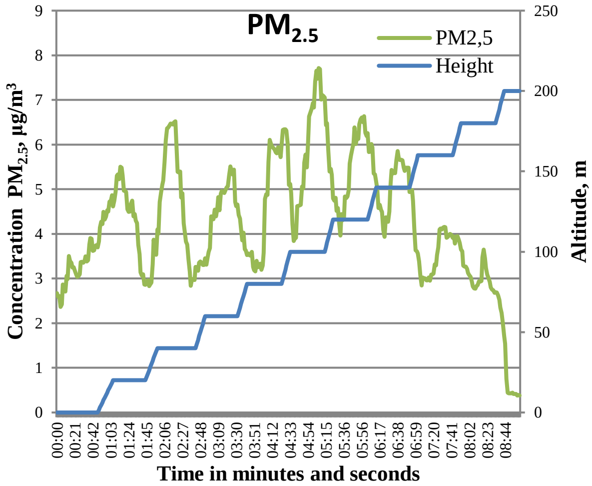
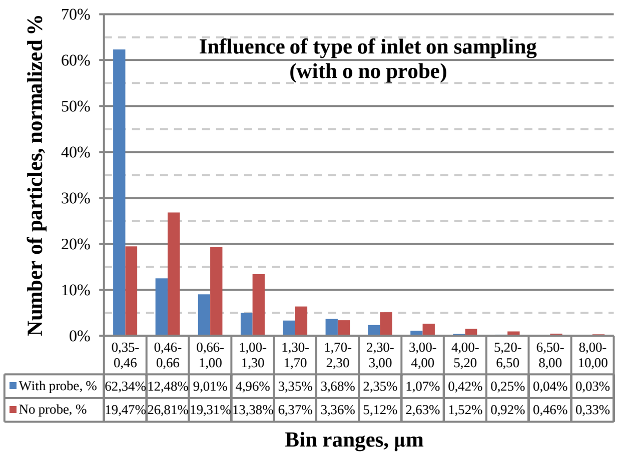


Fig. 5. PM$_{2.5}$ concentration relation with the altitude

C. Variable Wind Speed Experiment

A number of studies have shown that factors such as wind speed and direction, air suction angle and nozzle shape influence the measured concentrations of PM monitors [10]. For these reasons, particulate matter should be measured under isokinetic and iso-axial conditions. To estimate how the particle size distribution of the test air is affected by different wind speeds, the data is normalized. Normalization is done by calculating the shares of the average number of particles falling into their size in the various bins.

Fig. 6 shows data for different types of inlets (with or without a nozzle) classified by particle size diameter (using the OPC-N3 bins). It is observed that for the particles ranging from 0.35 to 0.46 μm, the greatest differences are found in use and without the use of a probe. When using the probe, the number of particles exceeds by more than 40%. They are followed by particles ranging from 0.46-0.66 μm, where the percentage difference is almost 10%, but here the elevation is in non-probe measurements. This tendency is maintained for particles with a size up to about 3 μm.



	0,35-0,46	0,46-0,66	0,66-1,00	1,00-1,30	1,30-1,70	1,70-2,30	2,30-3,00	3,00-4,00	4,00-5,20	5,20-6,50	6,50-8,00	8,00-10,00
With probe, %	62,34%	12,48%	9,01%	4,96%	3,35%	3,68%	2,35%	1,07%	0,42%	0,25%	0,04%	0,03%
No probe, %	19,47%	26,81%	19,31%	13,38%	6,37%	3,36%	5,12%	2,63%	1,52%	0,92%	0,46%	0,33%

Fig. 6. Influence of type of inlet on measured concentrations

Fig. 7 visualizes data for different wind speeds (1.5 m/s and 3.2 m/s) classified by particle size diameter (using the OPC-N3 bins). It is observed that for all bins (particle sizes) the difference between the number of particles in a bin for different wind speeds is less than 2 %.

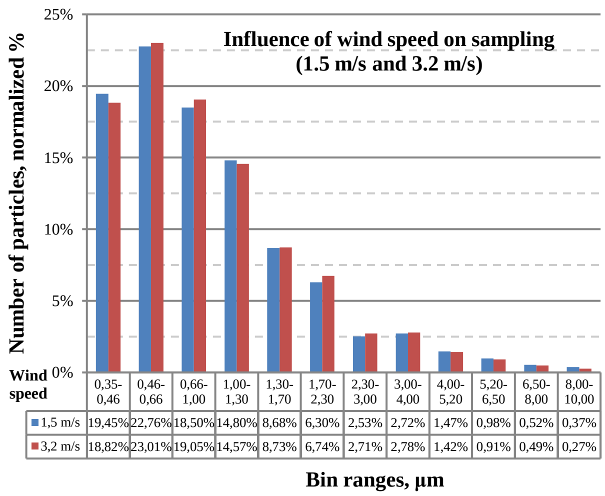


Fig. 7. Influence of wind speed on measured concentrations

D. Point Source Experiment

The test was conducted on 11 May 2019 in order to evaluate the integration of the system. The test used a fire in an open area as an airborne particulate source. The UAV was programmed to fly around the fire for approximately 5 minutes with a probe. Data collected from the UAV for the air quality sensor is shown in Fig. 8.

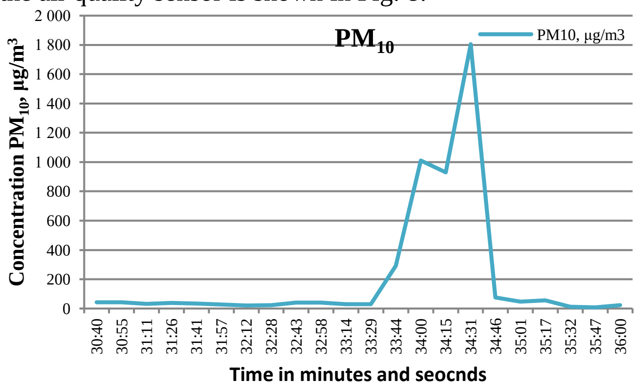


Fig. 8 Particulate matter sampling over open fire

IV. Conclusion

In this study, the UAV integrated with mobile monitoring sensors is used to collect $PM_{1/2.5/10}$ concentration data up to 200 m in urban environments on the territory of TU Sofia. The study demonstrates that modified UAV bearing sensors is an effective and flexible tool for measuring the vertical distribution of $PM_{1/2.5/10}$ concentrations and atmospheric parameters. Experiments show that overall the concentration of $PM_{2.5}$ decreases from certain point of altitude. Only sudden changes in weather can distort this trend.

UAV allows for a better description of the pollutant behavior in urban areas. We have also shown that it is a powerful tool for measuring concentrations near a probable source of pollutants.

Acknowledgment

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