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CONSIDERATIONS ON THE CURRENT STATE OF SENSORS ATTACHED TO DRONES APPLICATIONS IN ENVIRONMENTAL QUALITY MONITORING

Anca ȘERBAN, Adrian LEOPA
“Dunarea de Jos” University of Galati, Romania
e-mail: anca.serban@ugal.ro, adrian.leopa@ugal.ro

ABSTRACT

Environmental pollution can be detected by installing special devices on the drone, called sensors, which will collect data on air, water, and soil quality. The topic of using drones with sensors is currently known and is applied in various fields such as agriculture, meteorology, hydrology, marine and oceanographic prospecting, gas leak inspection, environmental monitoring, etc. Air, water, and soil sensors and collectors attached to drones are used to detect and collect contaminants. The remote sensing method uses multispectral optical and thermal sensors for modelling and mapping applications.

KEYWORDS: sensors, UAV, environment, pollution, monitoring

1. Introduction

Today, drones are playing an increasingly important role in the civilian field. Civilian drones are able to fly for tens of minutes and are maneuvered from the ground and from a distance. Civilian drones are controlled wirelessly via remote control or applications installed on the smartphone with an operating system. There are several types of drones that vary depending on the achieved performance and the technical characteristics: camera capabilities, flight distance, or battery life [1].

UAVs refer to a wide range of different platforms that due to their physical size and power differ in the simplicity of operation, flight endurance, and capabilities.

There are several UAVs used in various applications namely multi-rotor drones, rotary wing, and fixed-wing drones. They have the same qualities, but the multi-rotor UAV is more stable and easier to control [1].

Fig. 1. *Fixed-wing UAV, equipped with four vertical rotors, VTOL PD-1, Ukrspecsystems* [2]

Fig. 2. *Multi-rotor drone - Octocopter Predator FAE 1115* [3]

The main areas of civilian applications that use drones are [1]:
- monitoring in agriculture;
- monitoring in forestry;
- environmental monitoring
- gas leak detection;
- fire detection;
- monitoring of photovoltaic systems;
- wind turbine inspection;
- data acquisition in hard-to-reach areas;
- monitoring of constructions and buildings;
- power line control;
- aerial surveillance and photography;
- archeology.

In environmental monitoring, there are two types of sensors in a drone: flight control system sensors and sensors for collecting and analysing samples.

The selection of appropriate sensors for measuring the environmental parameters is a very

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important task. The sensors should have a short enough response time appropriate for in-flight measurements, the data exchange interface should not exceed the limits and specifications set by the airborne hardware and the price should be within reasonable limits [4].

Mobile real-time commercial micro-sensors attached to UAVs are used for the measurement of pollutants with high resolution but also capturing the dynamics of pollutants in the environment. A UAV equipped with multi-pollutant sensors requires a design that allows inserting and incorporating several sensors with distinct operating modes. Each sensor is sensitive to a particular pollutant and produces specific signals [5].

UAV remote sensing functions that should be covered by the sensors installed onboard include electromagnetic spectrum sensors, biological sensors, and chemical sensors. The UAV-mounted sensors can be utilised for air temperature and parameters, as also atmospheric conditions [6].

In environmental monitoring, current research and use aim data acquisition of air, water, and soil samples with onboard sensors. Sensors can acquire data on environmental parameters such as temperature, humidity, air pressure, pH, nitrate, ammonia, oxides and other air, soil, and water pollutants. The success of the data collection depends on the weather conditions and operating restrictions caused by the relief or urban infrastructure, but also on the performance of the sensors used in the data acquisition (image, sound, temperature, etc.) [7].

2. Applications of drones with sensors for environmental monitoring

The research revealed new applications for drones, such as collecting samples for air, soil, and water quality for laboratory analysis or assessing in situ with onboard sensors.

A drone is different from a satellite, only in that it operates at a much lower altitude. This allows for much greater detail with less atmospheric interference [8].

The near-range monitoring from drones (UAV or UAS) is a remote sensing method of the airborne oil spill. Near-range monitoring of oil spills includes mapping of relative and absolute oil layer thickness, as well as classification of the type of oil. Different types of oil sensors are: aerial photography and video, multispectral optical and thermal sensors (visible, UV, thermal-IR, UV-IR sensors), microwave radiometers, hyperspectral sensors, laser, radar and integrated airborne sensing systems. Drones can also be used to monitor localized oil pollution such as oil leakage from shipwrecks [9].

In Figures 3 and 4, the thickest emulsions show the highest heat emission (white areas in Fig. 3) while thinner emulsions appear cooler (darker) than the surrounding water due to petroleum's lower emissivity properties [10].

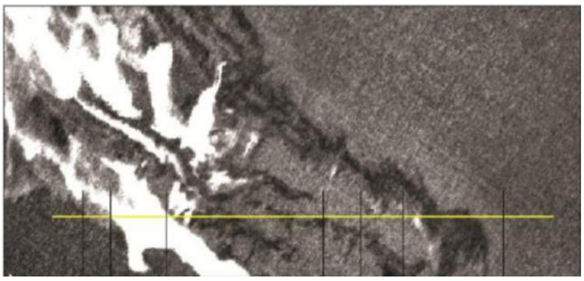

Fig. 3. *Thermal IR of a large area of emulsified oil during the Deep Water Horizon spill* [10]

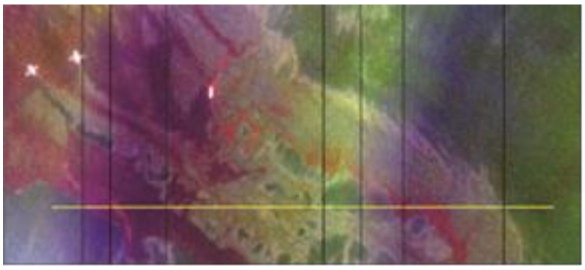

Fig. 4. *Visible multispectral sensor using 450, 551 and 600 nm bands for the blue, green and red image components* [10]

The sensor technology measures a variety of air pollutants and natural components. These have been developed for the Internet of Things (IoT) projects in which mass-produced sensors are placed throughout a city to produce real-time air quality information but are also suitable for drone platforms. The available sensors include temperature, humidity, air pressure, CO, CO_2, O_2, O_3, NO, NO_2, SO_2, NH_3, CH_4 (and combustible gases), H_2, H_2S, HCl, HCN, PH_3, Cl_2, and particulate matter (PM1, 2.5 and 10). Potential applications include: sampling pollution point sources, such as an industrial or a construction site, where air samples are taken by the drone from above a site, compared to those taken near-ground; sampling vertically can predict changes in ground-level pollution, especially of particulate matter [8].

The unmanned aerial vehicle (UAV) has a high capacity for collecting air quality data by spatial and temporal measurements with high resolution.

The vertical atmospheric measurements are very useful for evaluating and forecasting air pollution, especially in high-building metropolitan areas.

The use of unmanned aerial vehicles (UAV) has shown that its applications in air pollution monitoring studies are effective [5].

Research in atmospheric aerosols showed the vertical profiles of black carbon concentration determined with the micro-aethalometer AE-51 mounted on a drone. Thus, the black carbon section (Fig. 5) was almost stable, with variations in some regions around 2.5 μg/m^3. The results showed that the use of drones for research into atmospheric aerosols is performing [11].

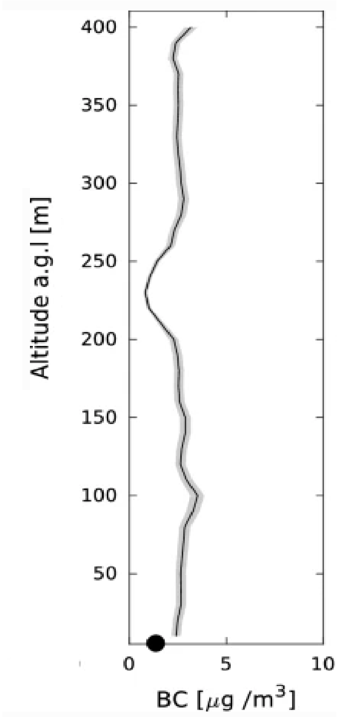

Fig. 5. *The black carbon concentration* [11]

A study achieved through a $PM_{2.5}$ sensor and a NO_2 sensor when the drone was not moving but was floating showed a difference in readings. Thus, when the drone was on the ground, the readings using both sensors showed a normal distribution of data [5].

But when the UAV was in the air, the sensor readings changed because of the electronic interference from the UAV. However, the $PM_{2.5}$ concentrations may be compared with those obtained by the reference method [5].

Other researchers are working on drones that can collect water samples. Monitoring of natural and public waterways is improved by drone sampling. The available sensors for in situ water analysis include temperature, conductivity (a proxy for salinity), pH, dissolved oxygen, and oxidation-reduction potential [8].

The drone-mounted sensors used in the design of maps and models for the quality and quantity of water bodies appeared around 2013 [12].

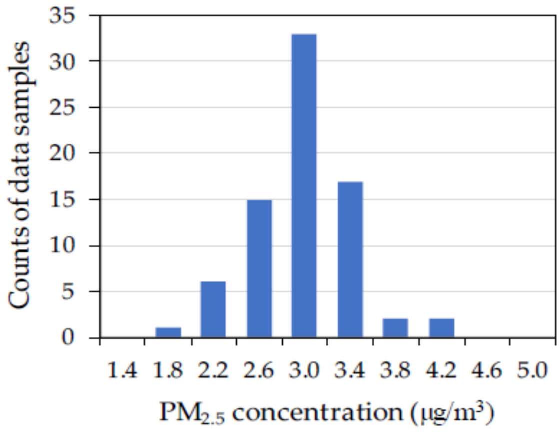

Fig. 6. *$PM_{2.5}$ measured on ground* [5]

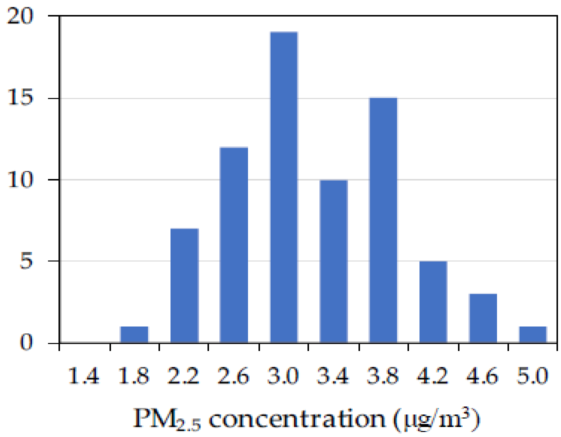

Fig. 7. *$PM_{2.5}$ measured in air* [5]

The widely researched water quality parameters included conductivity, salinity, water reaction pH, chloride Cl-dissolved oxygen DO, total suspended solids (TSS), chlorophyll, turbidity, potassium cation K^+, ammonium nitrogen (NH_4^-N), sodium (Na^+), biological oxygen demand BOD, magnesium (Mg^{2+}), total phosphorous, orthophosphate (PO_4^-P), total nitrogen, iron ions (Fe^{2+}, Fe^{3+}), chemical oxygen demand COD, zinc (Zn^{2+}), calcium (Ca^{2+}), manganese (Mn), copper (Cu), bicarbonate HCO_3^-, cadmium (Cd), chromium (Cr), total coliforms and total hardness. The satellite's remotely sensed data were mostly used to describe the dynamics of the parameters listed above [12].

The studies based on drone remotely sensed data were conducted for mapping and monitoring chlorophyll content and turbidity in lakes, ponds, and dams.

The quality of irrigation water needs continuous monitoring if the aim is to have quality crops and reap rich harvests. COD, conductivity, pH, TSS, DO, and turbidity are essential indicators of water used for irrigation in agriculture [12].

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The drone technologies use sensors for water remote sensing applications, such as multispectral sensors and hyperspectral sensors. The hyperspectral sensors that collect data on water quality by remote sensing are very sensitive to low-intensity changes in water quality parameters such as chlorophyll and TSS concentrations [12].

The multispectral sensors retrieve data from the electromagnetic spectrum at a very high spatial resolution. Thus, those sensors operate in the visible spectrum also red edge and the near-infrared spectrum. In order to monitor the water quality parameters, the predominant working spectrum is the visible (blue and green) and the NIR (near-infrared radiation) wavebands. [12].

A study of water quality from a 1.1 ha agricultural pond using UAV developed a hexacopter designed with an open-source electronic sensors platform that measures the temperature, electrical conductivity (EC), dissolved oxygen (DO), and pH. The measurements collected by an open-source multiprobe meter (OSMM) mounted on the unmanned aerial vehicle (UAV) were compared to the measurements made by a commercial multiprobe meter (CMM) [13].

The commercial multiprobe meter (CMM) contained a portable SENSION meter for measuring pH and EC and a portable HQ10 meter with DO and temperature probes. The OSMM was a combination of a water sensor node and an open-source electronic platform. The water sensor node consisted of EC, DO, pH, and temperature circuits, and was integrated with a microcontroller [13].

Fig. 8. *The open-source multiprobe meter (OSMM) components* [13]

In table 1, the terms mean N: Number, SD: Standard deviation. The differences between the OSMM and CMM measurements for DO, EC, pH, and the temperatures were 2.1 %, 3.43 %, 3.76 %, and <1.0 %. Although EC and temperature values were statistically different, they followed a similar pattern [13].

Table 1. *Descriptive statistics for water quality parameters obtained by the OSMM and CMM* [13]

Quality Parameter	OSMM			CMM			Difference (%)
	N	Mean	SD	N	Mean	SD	
Temp. (°C)	195	27.15	0.93	39	24.79	0.58	2.33
EC (μS/cm)	195	49.2	9.69	39	64.73	4.57	3.43
pH	195	8.43	0.86	39	8.12	0.36	3.76
DO (mg/L)	195	9.05	0.27	39	8.87	0.49	2.08

Soil monitoring is also a current concern in the UAV technologies using sensors.

Research was conducted to obtain the physical properties of the peat soil and to correlate with the healthiness of the pineapple crop. The data was collected from the site using DJI-Phantom 4 drone and Mapir Survey 3 multispectral camera. The peat soil samples were taken and were transferred to the laboratory to be tested for moisture content and pH test [14].

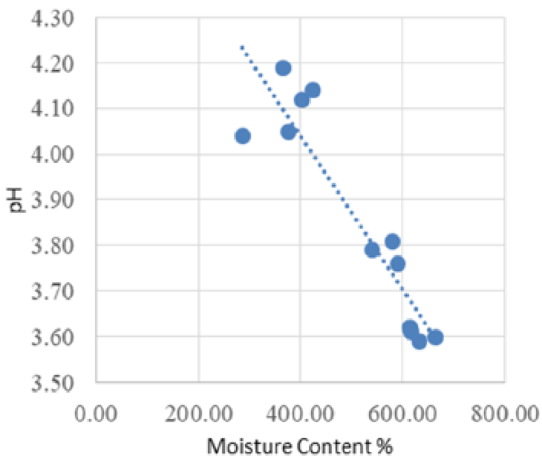

Fig. 9. *PH value and moisture content* [14]

The moisture content of the soil was increasing to 100 % of water ratio, while the value of pH of acidity was decreasing. Both the physical properties of the peat soil were dominating factors contributing to the healthiness of the pineapple crop in the research area [14].

Another study used hyperspectral sensors mounted on a UAV to evaluate and map soil salinity. The quantitative assessment and evaluation of soil salinity at the field-scale level were achieved using electromagnetic induction equipment (EMI) and a hyperspectral camera installed on a UAV platform. The calibration of apparent electrical conductivity (ECa) values measured by the EMI sensor was

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performed by the empirical line method using the lab measured electrical conductivity derived from soil samples. The ECA was measured with the EM38-MK2 sensor by first inducing an electrical current in the soil. In order to correlate the spectral information to soil salinity contents, the random forest (RF) regression was used. An empirical linear regression was established between the ECa and $EC_{1:5}$ [15].

Table 2. *The points values of ECa and the $EC_{1:5}$ measured by hand-hold EM38-MK2 and chemical analysis* [15]

Field	Conductivity	Descriptive Statistics (EC_a, mS m^{-1}; $EC_{1:5}$, dS m^{-1})		
		Min	Max	Mean
A	EC_{ah}	571.15	955.72	765.05
	EC_{av}	598.15	1065.57	846.74
	$EC_{1:5}$	20.25	54.90	37.64
B	EC_{ah}	450.20	1092.15	830.47
	EC_{av}	585.67	1035.90	824.51
	$EC_{1:5}$	7.20	14.68	11.73
C	EC_{ah}	695.86	1126.99	890.15
	EC_{av}	560.17	955.56	778.00
	$EC_{1:5}$	9.64	19.64	14.11

In Table 2, the highest EC value (47.14 dS m^{-1}) of the surface soil was measured in field A which had no vegetation at all. The spectral reflectance of crops on the soil would change due to poor water absorption under conditions of salt stress.

The UAV platform used for establishing regression models between EC and soil surface reflectance turned out to be acceptable for collecting spectral information. In addition, the soil salinity evaluation was more accurate due to results for bare land and sparse vegetation area and less specific for dense vegetation area [15].

An aerial monitoring platform equipped with sensors for detection of specific contaminants, named AWISEM (Air-Water Innovative System for Environmental Monitoring) was aimed to be a mobile aerial and aquatic vehicle that should contain: A) an aerial and aquatic mobile monitoring platform, with an innovative sustentation system, having the capability to fly and also to float in an aquatic environment; B) two distinct sets of sensors, based on CNT (carbon nanotube-polymer) composites with high sensitivity for the monitoring of either aerial or aquatic contaminants. The sensing membranes (thin layers) for two types of sensors are able to detect contaminants such as ammonia - in air and nitrites - in water [16].

3. Conclusions

The digital revolution has the potential to change the way we approach monitoring and sensing important fields. Combining drone technology with high-tech sensors, reliability, dynamics, and efficiency are achieved in applications such as monitoring water bodies, soil fertility, irrigation, planting trees, air pollution, etc.

The UAV system integrates sensors as electromagnetic spectrum sensors, gamma ray sensors, airborne wireless sensor network, biological sensors and chemical sensors, etc. for these sensing and monitoring applications.

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