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DEVELOPMENT OF AN AIR-QUALITY-SENSORS MONITORING SYSTEM FOR INTEGRATION INSIDE A DRONE

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KEY WORDS

Outdoor air quality, sensors, VOCs, Ozone, NO_2, meteorological parameters, drone upload

ABSTRACT

1. Introduction

Outdoor air pollution is a major environmental risk influencing world population's health and life quality. In cities as well as rural areas, it was estimated to cause 3 million premature deaths worldwide in 2012 [1]. Among the various compounds present in outdoor air, Volatile Organic Compounds (VOCs), Nitrogen Oxides (NO_x) and ground level Ozone (O_3) play a crucial role in air pollution. More specifically, VOCs and NO_x react in presence of light resulting in photo-oxidation products such as O_3, NO_2, PeroxyAcyl Nitrates (PANs) and aldehydes [2]. A series of reactions including the latter compounds and their precursors are responsible for the photochemical smog [2] that many cities experience nowadays. The 2005 "WHO (World Health Organization) Air quality guidelines" offer global guidance on thresholds and limits for key air pollutants that pose health risks. For instance, in the case of O_3 a 100 $\mu g/m^3$ 8-hour mean value has been established, while for NO_2 a 40 $\mu g/m^3$ annual mean and a 200 $\mu g/m^3$ 1-hour mean have been set. However, in 2014, 92% of the world population was living in places where the WHO air quality guidelines levels were not met [1]. These observations highlight the importance of outdoor air monitoring which is currently mandatory in European countries [3]. For this purpose, air quality monitoring ground stations are used. In parallel, to better respond to the need for outdoor air pollution monitoring and mapping, the integration of monitoring systems in drones that can fly in the range of the atmosphere seems to be very promising. Such a solution is proposed in this work, as part of the ELCOD (Endurance LOw Cost Drone) Project.

2. Conception of the monitoring system

Two different proposed designs for the drone are presented in Fig.1. The drone will be powered by fuel cells to increase the flight range and to avoid emissions interfering with the sensors' measurements. The payload refers to the sensors-based monitoring system. Important constraints had to be met for the integration of the later in a drone, such as low weight, limited dimensions as well as autonomy and low energy consumption, all balanced with the major necessity for accurate monitoring. Therefore, a microfluidic system based on industrial sensors is suggested in this work.

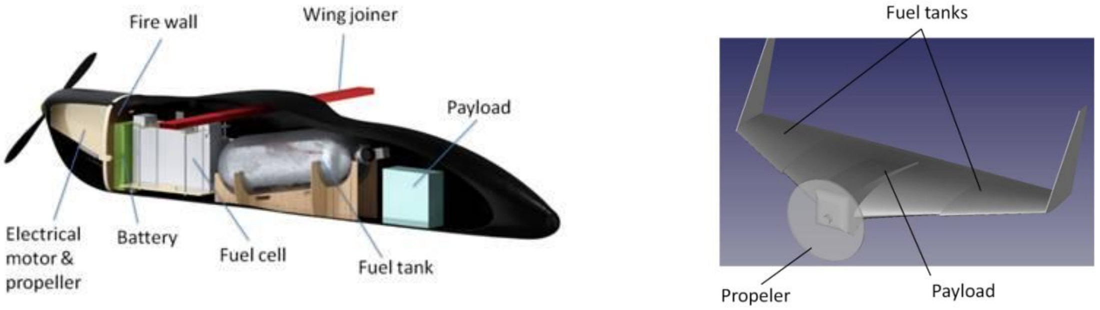


Figure 1: Proposed drone designs (Payload refers to the sensors-based monitoring system).

Chemical sensors meeting the desired performance and characteristics have been chosen for monitoring of VOCs (2 different sensors), NO_2 and O_3. Sensors for Temperature (T), Relative Humidity (RH) and Pressure (P) are also proposed to measure meteorological conditions. Tab.1 summarizes the industrial sensors and their specifications, as given by manufacturers.

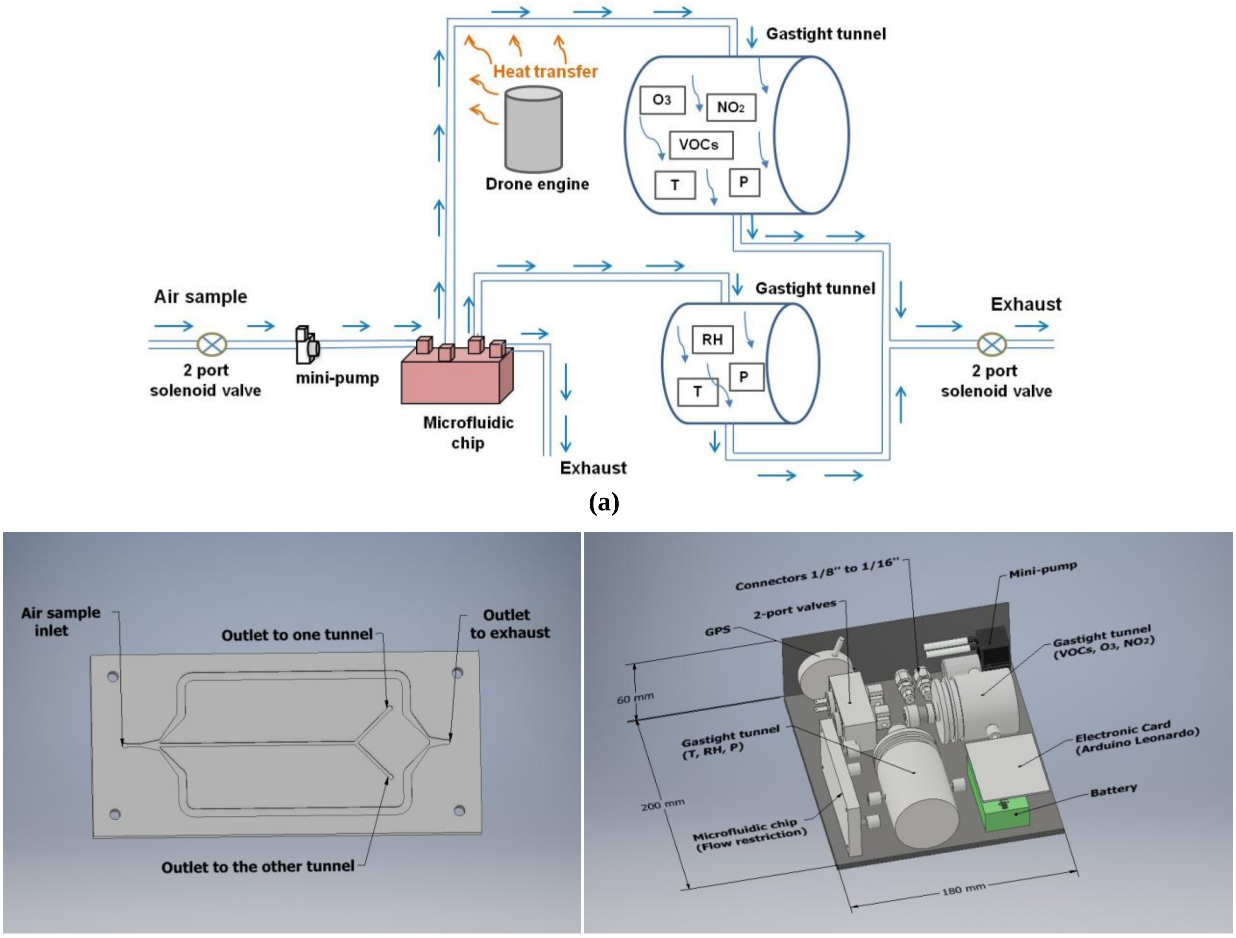
Table 1: List of industrial sensors and their specifications according to manufacturers.

Pollutant / Parameter	Sensor (Manufacturer)	Range	Accuracy	Response time
Volatile Organic Compounds (VOCs)	MiCS-5524(SGX Sensortech)	1 -1000 ppm [a]	-	-
	MiCS-VZ-89TE (SGX Sensortech)	0 -1000 ppb [b]	-	< 5 s
Ozone (O_3)	MQ131 (SAINSMART)	10 - 2000 ppb	-	-
Nitrogen Dioxide (NO_2)	NO_2-A43F (Alphasense)	0 - 20 ppm	-	$t_{90} < 60$ s [c]
Temperature (T)	TSic™ 301 TO92 (IST)	-50 to +150 °C	± 0.3 K [d]	-
Relative Humidity (RH)	HIH-5030 (Honeywell)	0 -100 %	± 3 % [e]	5 s [f]
Pressure (P)	BME 280 (Bosch Sensortec)	0.3 -1.1 bar	-	1s

[a] Given for CO; [b] Given for isobutylene equivalent tVOCs ; [c] Time to reach 90 % of 2 ppm from 0 ppm; [d] In the range of 10-90 °C, [e] In the range of 11–89 % ; [f] In slow moving air

For accurate and reliable measurements during flight, the sensors will be confined inside two gastight cylindrical tunnels (Fig.2a). One tunnel will contain the chemical sensors and the other the sensors of meteorological conditions. In the tunnel of chemical sensors a T and a RH sensor will be also included for calibration purposes. Two 2-port solenoid valves and a mini-pump will be integrated to the microfluidic system to enable sampling during motion and stationary sampling, respectively. Environmental conditions can have an important influence on the sensors performance. More specifically, the air sample is expected to have very low temperature and a very high flow rate due to the external ambient temperature and the high speed of the drone (superior to 90 km/h), respectively. The high flow rate can decrease the performance in the case of all sensors, whereas the exterior temperature influence is expected only for the chemical sensors (VOCs, NO_2, O_3). To ensure the desired continuous air flow rate during sampling, a microfluidic MEMS-based chip will be developed and used to create the necessary flow restriction inside our system (Fig.2b). On this chip, the air will be firstly divided in 3 different channels, a central narrower and less deep one and two wider and deeper. Thus, a restricted air flow will be achieved in the central channel, while the rest of the air sample will be exhausted by the two wider and deeper channels. Later on, the central channel is also divided at two, providing two different outlets. Form one outlet the sample will be directed towards the tunnel with T, RH and P sensors (Fig.2a). From the other outlet the sample will move towards the tunnel of chemical sensors but prior it will pass near the drone's engine, to be heated up, thus enabling

the protection of the chemical sensors from low temperatures. Temperature and pressure measured close to the chemical sensors will be used to correct data based on a previous laboratory calibration.
The dimensions of the microchannels of the microfluidic chip are yet to be determined and validated by flow modeling. Necessary electronics as well as a battery will be integrated to render the system functional and autonomous. The total monitoring system will not exceed 1.5 kg in weight and will occupy a place of 200x180x60 mm (Fig.2c). Furthermore, the energy consumption is expected to not exceed 20 W.



(a)

(b) **(c)**

Figure 2: Schematic representation of the microfluidic system (a); Proposed design of the microfluidic chip for flow restriction inside the system (b) and 3D design of the total monitoring system (c)

3. Evaluation of sensors' performance

The two metal oxide VOCs sensors (MiCS-5524 and MiCS-VZ-89TE, SGX Sensortech) were tested with a continuous flow of synthetic air, as indicated for their best function. Injections of BTEX (Benzene, Toluene, Ethylbenzene and Xylenes) - a family of VOCs - were made at a volume of 200 µL. BTEX concentration varied in concentrations between 30 and 600 ppb and 3 injections were repeated for each concentration. Fig.3 presents the calibration curves of the VOCs sensors, corresponding to the mean injection peak area as function of BTEX concentration. For both sensors the injection peak area increases perfectly linearly with gaseous BTEX concentration. Detection limits were calculated considering a usual signal/noise ratio equal to 3. For MiCS-5524 the detection limit was calculated to be 44 ppb. This limit is inferior to the measurement range of 1-1000 ppm, given by the manufacturer (Tab.1). However, this can be explained by the fact that the latter is given for CO and not BTEX and that the tests were conducted in controlled laboratory conditions. For MiCS-VZ-89TE the detection was calculated to be 31 ppb, which is an expected value since the measurement range of the sensor is 0-1000 ppb but given for isobutylene (Tab.1). Furthermore, the response time of this sensor to the injections was measured to be 4s, in good agreement with the manufacturer value of < 5s (Tab.1).

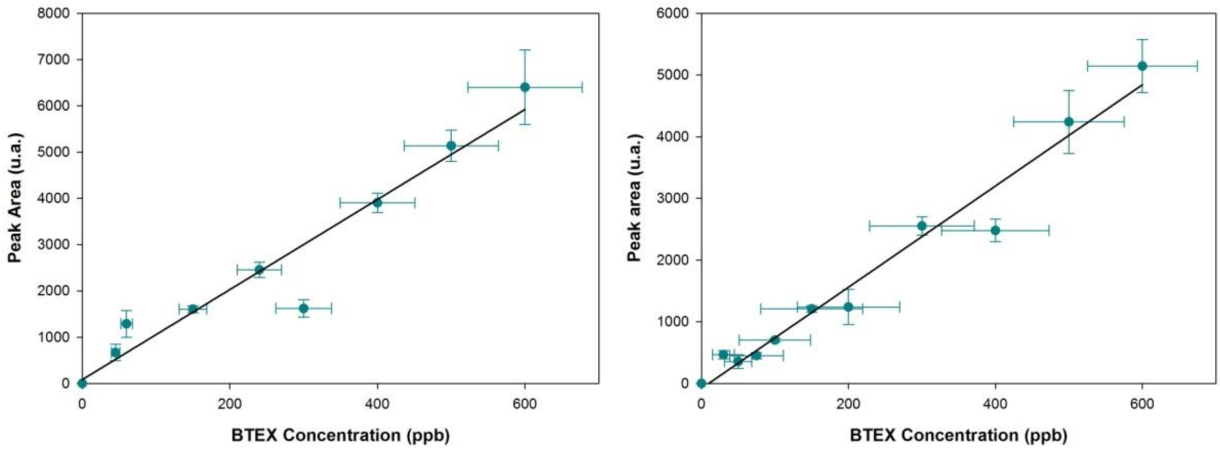


Figure 3: Calibration curves of VOCs sensors with BTEX. Left: MiCS-5524 (SGX Sensortech); Right: MiCS-VZ-89TE (SGX Sensortech). The vertical errors correspond to the standard deviation of peak areas calculated for the three injections. The horizontal errors refer to the uncertainty on the BTEX concentrations, taking into consideration the initial uncertainty of the BTEX cylinder and the precision of flow controllers used for dilution purposes.

The O_3 and NO_2 sensors will be evaluated in the future through continuous real-time monitoring and calibrated if necessary though injections of known concentrations of the pollutants in the desired range. The T, RH and P sensors will be tested inside an unoccupied room either confined or ventilated (closed or open windows, respectively). Finally, once the whole system developed, a comparison with ground station monitoring stations will be made prior to the integration inside the drone.

4. Conclusions and Perspectives

In this work, we report the conception and development of a sensors-based microfluidic monitoring system for outdoor air quality, meeting all the specifications for integration inside an endurance drone. This new approach presents new possibilities regarding measurements of major outdoor air pollutants and pollution mapping in urban and rural environments. This system is also flexible and autonomous enough to be used for indoor air monitoring, with the proper modifications. For instance, the VOCs sensors could be coupled to a MEMS-based micro-preconcentrator to decrease the detection limit lower than the targeted benzene guideline value of 1.6 ppb, as imposed by the current regulation [4].

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