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MAV payload: An air-quality monitoring system for integration inside a drone

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ABSTRACT

Outdoor air pollution attracts great interest due to its influence on the environment and on human health. To respond to the necessity of outdoor air monitoring, this work presents the conception and development of a sensors-based air monitoring system that meets all the specifications to be integrated inside a drone. Sensors have been chosen to monitor Volatile Organic Compounds (VOCs), Nitrogen dioxide (NO_2) and Ozone (O_3) as well as Temperature (T), Relative Humidity (RH) and Pressure (P). A microfluidic chip consisting of a narrow central microchannel and two wider external microchannels will be added to the system, thus ensuring a satisfactory flow restriction as demonstrated by flow simulations (22% of the initial flow rate).The total monitoring system wil occupy a place of 250 x 170 x 105 mm^3 and its consumption will not exceed 10 W. The latter will be covered by a battery rendering the system autonomous. Two VOCs sesnors have been tested and calibrated by injections of BTEX (Benzene, Toluene, Ethylbenzene and Xylenes) and the results demonstrate very good linearity of the signal as function of BTEX concentration.

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 (NOx) and ground level Ozone (O_3) play a crucial role in air pollution. More specifically, VOCs and NOx 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 µg/m3 8-hour mean value has been established, while for NO_2 a 40 µg/m3 annual mean and a 200 µg/m3 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 troposphere seems

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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

One of the two different proposed designs for the drone are presented in Figure 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.

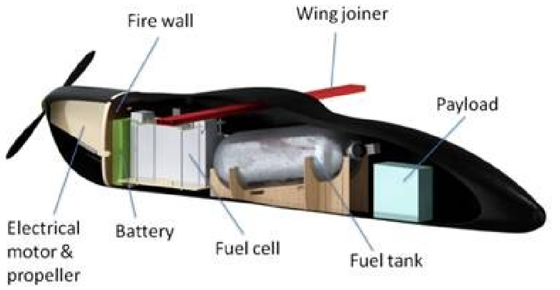
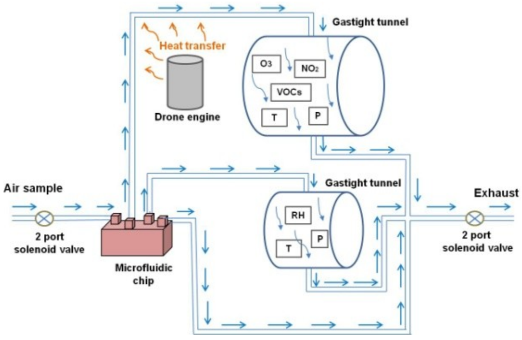


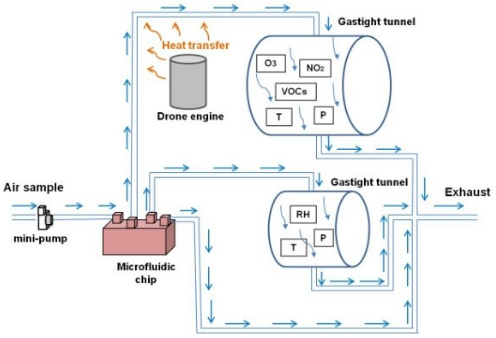
Figure 1 – One of the proposed drone designs (Payload refers to the sensors-based monitoring system).

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.

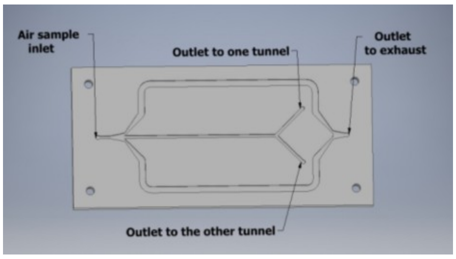
For accurate and reliable measurements during flight, the sensors will be confined inside two gastight cylindrical tunnels (Figure 2a and 2b). One tunnel will contain the chemical sensors and the other the sensors of meteorological conditions. In the tunnel of chemical sensors a T and a P sensor will be also included for calibration purposes. Two different system configurations are proposed to enable sampling during motion and stationary sampling, where 2-port solenoid valves (Figure 2a) and a mini-pump (Figure 2b) will be integrated, 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 (Figure 2c). 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 (Figure 2a and 2b). 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.



(a)



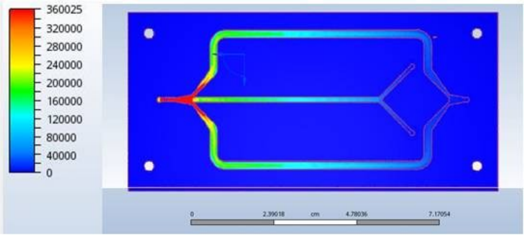
(b)



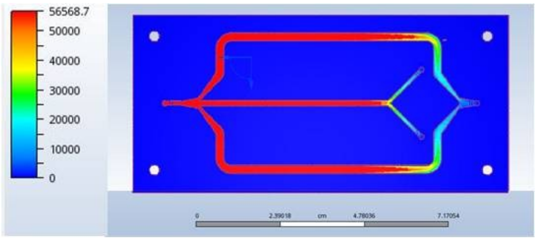
(c)

Figure 2 - Schematic representation of the microfluidic system for sampling during flight (a) and stationary sampling (b); Proposed design of the microfluidic chip for flow restriction inside the system (c)

The dimensions of the microchannels of the microfluidic chip were determined and validated by flow simulations (Autodesk CFD). The simulations were made with a 3D printing polymer as the chip material and for a total inlet of 1 L/min at 0 and 20 °C. Preliminary results indicated that with a central microchannel of 1.00 x 1.00 mm^2 and two external microchannels of 2.25 x 1.00 mm^2 a flow restriction can be achieved so that finally in the central microchannel we have only 22% of the initial flow rate (Figure 3a). This flow restriction is satisfactory for our system since it can protect the sensors while at the same time it enables reasonably quick air renewal. As demonstrated in Figure 3b this flow rate is afterwards equally divided in the two tunnels.



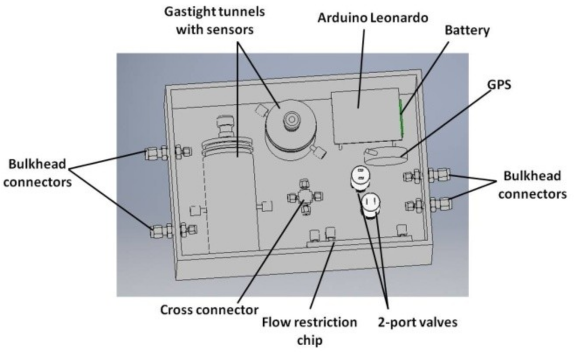
(a)



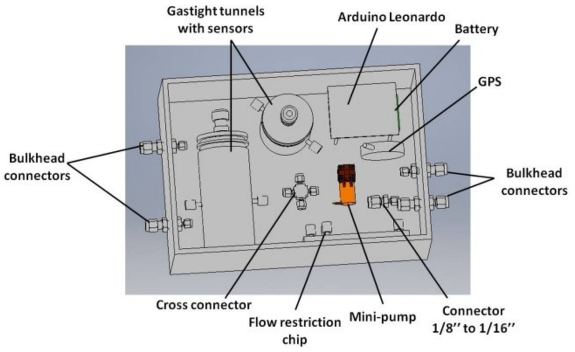
(b)

Figure 3 - Flow simulations on the microfluidic chip: Flow division between external and central microchannel (a); flow division between the two tunnels (b). The scale represents the velocity amplitude.

Necessary electronics and 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 250 x 170 x 105 mm^3 (Figure 4). Furthermore, the energy consumption is expected to not exceed 10 W.



(a)



(b)

Figure 4 - 3D design of the total monitoring system for sampling during flight (a) and stationnary sampling (b).

3 SENSORS' EVALUATION

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. Figure 5 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, whereas for MiCS-VZ-89TE the detection was calculated to be 31 ppb.

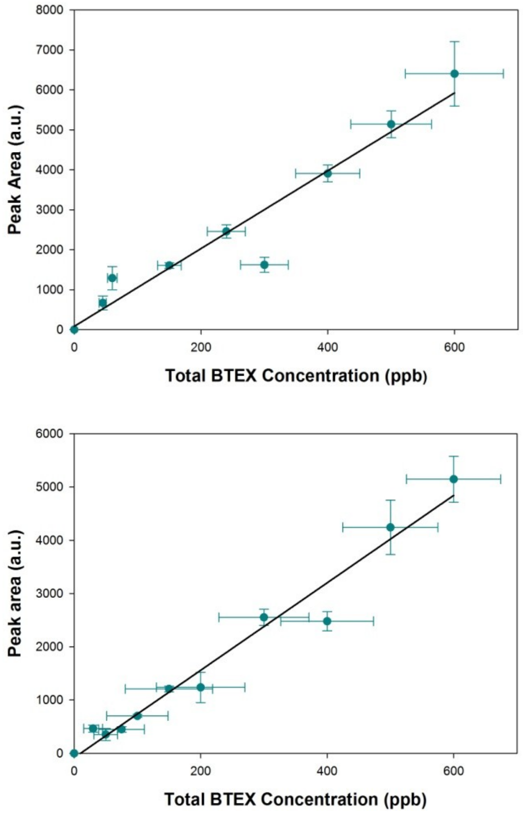


Figure 5 - Calibration curves of VOCs sensors with BTEX. Top: MiCS-5524 (SGX Sensortech); Bottom: MiCS-VZ-89TE (SGX Sensortech). The vertical errors correspond to the standard deviation of peak areas calculated for the three injections. The horizontal errors refer to the uncertainty on the BTEX concentrations, taking into consideration the initial uncertainty of the BTEX cylinder and the precision of flow controllers used for dilution purposes.

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.

ACKNOWLEDGEMENTS

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