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Environmental Monitoring System Using Unmanned Aerial Vehicles and WSN

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Abstract: In this work, a mobile real-time monitoring system for air quality is proposed. The developed system uses UAV (unmanned aerial vehicles) and WSN (wireless sensor networks), increasing the area of analysis and difficult access. The electronic instrumentation was integrated with an array of sensors, microcontroller, memory and RF modules. The acquired data is stored, processed and transmitted to a computer as a base station through wireless communication, where a developed graphical interface shows the concentrations of polluting gases present in the atmosphere at a minimum height of 10 to 300 m. The weight, size and power consumption of the miniaturized system are 100 g, 50×50×30 cm and 1.5 W respectively. The System was powered by an ion-Li 300 mA/hr battery. The system has the ability to detect important criteria pollutants such as carbon dioxide (CO_2), nitrogen dioxide (NO_2) and other polluting gases such as Ethanol (C_2H_5OH), Hydrogen (H_2), Ammonia (NH_3) and suspended particles PM2.5.

Keywords: Air quality, WSN, UAV, Criterial pollutants, Suspended particles PM2.5.

1. Introduction

In recent years, deaths caused by respiratory and cardiovascular diseases have increased by 10 %. In October 2018, the World Health Organization (WHO) stated that 93 % of the world's children breathe polluted air every day. According to this information, 1.8 billion children breathe air so polluted that their health and development are in serious danger. The WHO estimates that 600,000 children died in 2016 from acute respiratory infections caused by air pollution. This increase in atmospherically active gases leads to effects such as soil and water acidification [1]. In 2018, the Torreón city in Mexico, was ranked fourth in 248, as one of the most contaminated areas of ammonia on the planet [2].

In the absence of a national regulatory for the design and installation of air quality monitoring networks, the networks that currently operate in Mexico have different operational criteria and have strong limitations in terms of availability of financial, human and material resources. For this reason, the design of new networks to measure air quality, as well as the redesign of current networks and the expansion of their coverage, are necessary to improve their operation, by homogenizing the criteria of their establishment, operation and maintenance [3].

Previously, the measurement of air quality was carried out by non-continuous methods known as "wet chemistry" for gases and high volumes for suspended particles using complex and very expensive stationary equipment [4] to "collect" data. This paradigm is changing, new low-cost and easy-to-use sensors have been developed, providing high resolution and real-time data that can be "accessed" [5]. These attributes provide opportunities to improve a range of existing air pollution monitoring capabilities and provide avenues for new applications. The range of contaminants to be detected by sensors has been increasing. The appearance of new technologies such as UAV, WSN, the internet of things, advances in computing and communications achieves availability and accessibility of data in real time [6].

A key factor in establishing effective air quality monitoring programs is to assign the optimal location for monitoring stations based on five criteria (population, wind direction and spatial proximity to roads, industries and high traffic areas) that were considered the most important for assigning optimal locations for station monitoring [7]. A large number of developments have been reported to measure environmental parameters present in the air as well as the use of technologies. An investigation was made to measure the PM10 fugitive dust emission factors for a range of vehicles types and examined the influence of vehicle and wake characteristics on the strength of emissions from an unpaved road. This study was based on the determination of the vertical mass concentration profile, the speed and direction of the ambient wind, and the time it took to generate a trail of dust when passing through instrumented towers [8]. Another work, determined that the contribution of methane CH_4 comes from road traffic and domestic heating, revealing that heating accounts for more than 80 % of the observed CO_2 flows. CH_4 flows expressed as CO_2 equivalents represent approximately 8 % of CO_2 emissions, ranging from 16 % in summer to 4 % in winter and, therefore, cannot be neglected when assessing the impact of cities on the greenhouse effect [9]. On the other hand, by 3D computational model predicting extent of gas leakage was made based on the building location using Google Earth. The system was based on the concentration differences at the near wall and far wall, and the velocity field change with the leakage time, to provide reliable data for the city gas safe operation and emergency management [10]. Used on a dedicated Unmanned Aerial Vehicle (UAV) a new instrument was made to map NO_2 columns at high spatial resolution allowing to subsample satellite measurements within the extent of a typical ground pixel. The instrument was based on a compact ultra-violet visible spectrometer and a scanner to achieve whiskbroom imaging of the trace gases fields. Including the housing and the electronics [11]. A system online GPRS-Sensors Array was done integrated a Mobile Data-Acquisition Unit (Mobile-DAQ, based a microcontroller, sensors arrays and GPS) and a fixed Internet-Enabled Pollution Monitoring Server (Pollution-Server and Google Maps to display real-time pollutants), to monitoring air pollutants levels (CO, NO_2, and SO_2) [12]. The development of these devices allow emissions into the atmosphere to be measured, which would establish permissible limit values that do not present risks to the health of the population and adverse effects to the environment. Other results of an important investigation, shows a study for 10 years where the presence of ammonia affects air quality with consequences on human health, the environment and climate change. Anthropogenic emissions of ammonia dominate the natural ones and originate mainly from agricultural, domestic and industrial activities. The critical ammonia emission points of the world were identified and categorized and quantified using a high resolution map of atmospheric ammonia observed by IASI satellite. In the study, 248 critical points with diameters less than 50 kilometers were located, associating them with specific agricultural and industrial sources. This will lead to better environmental and health impact assessments of atmospheric ammonia and the implementation of appropriate nitrogen management strategies [13]. One of this critical points was located in Torreon, Coahuila, Mexico which is the fourth place of concentration of ammonia in the world. This was the reason the engineering academy started this research project. In this work, a mobile real-time monitoring system for air quality is proposed. The developed system uses UAV unmanned aerial vehicles and WSN wireless sensor networks. The system has the ability to detect important criteria pollutants such as carbon monoxide (CO), nitrogen dioxide (NO_2) and other polluting gases such as Ethanol (C_2H_5OH), Hydrogen (H_2), Ammonia (NH_3) and Propane (C_3H_8).

2. Fundamentals

2.1. Standards by Environmental Protection

One of the first standards and measurement systems established for the control of pollutants was born in the United States under the Clean Air Act in 1963, known as NAAQS (National Ambient Air Quality Standards) and established by the Environmental Protection Agency (EPA). This standard establishes concentration levels over a set period of time of the following contaminants:

- Carbon monoxide (CO);
- Lead (Pb);
- Nitrogen dioxide (NO_2);
- Ozone (O_3);
- Suspended particles:
  - PM10 ($d<10$ μm);
  - PM2.5 ($d<2.5$ μm).
- Sulfide dioxide (SO_2).

From NAAQS, the IMECA system (Metropolitan Air Quality Index) was created in 1982, it is a Mexican standard that uses the bases established by the NAAQS to monitor air quality, at that time focused on

Mexico City and its growing problem of air pollution. The IMECA system provides a standardized way to measure the concentration of pollutants throughout the country, however, it is necessary to take into account a couple of peculiarities about this system. The first is the fact that IMECA was originally conceived as an adaptation with more permissible threshold values than the NAAQS, being the logic for this decision that, if the values established by the American standard were strictly taken, Mexico City would look in a perpetual state of environmental contingency, so it was decided to relax the limits of health risk. The other aspect to consider is that the value indicated by the IMECA scale only gives us the value of the pollutant that presents the greatest risk at that time, being possible that the concentration of other pollutants can also be found at dangerous levels without being reflected in the value final delivered by the scale [14].

2.2. Different Air Quality Standard Breaking Points

A breaking point is defined as the maximum acceptable level of a given substance. Any concentration above said measured is considered harmful to public health and the environment. Table 1 indicates the maximum levels allowed by each of the standards.

Table 1. Standard breaking points.

	IMECA (Mexican standard)		NAAQS (US Standard)		*WHO Guidelines	
Pollutant	**Averaging Time**	**Level**	**Averaging Time**	**Level**	**Averaging Time**	**Level**
Ozone(O_3)	1 hour	0.11 ppm	8 hours	0.07 ppm	8 hours	0.05 ppm
Carbon Monoxide (CO)	8 hours	11 ppm	8 hours	9 ppm	-	-
Nitrogen Dioxide (NO_2)	1 hour	0.21 ppm	1 hour	0.1 ppm	1 hour	0.1045 ppm
Sulfur Dioxide(SO_2)	24 hours	0.13 ppm	1 hour	75 ppb	24 hours	7.51 ppb
PM 10	24 hours	120 µg/m^3	24 hours	150 µg/m^3	24 hours	50 µg/m^3
PM 2.5	24 hours	65 µg/m^3	24 hours	35 µg/m^3	24 hours	25 µg/m^3

*World Health Organization

2.3. Particulate Matter PM2.5

Particle pollution, also called particulate matter or PM, is a mixture of solids and liquid droplets floating in the air. Some particles are released directly from a specific source, while others form in complicated chemical reactions in the atmosphere. They consist of a complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air. The main components of PM are sulfates, nitrates, ammonia, sodium chloride, soot, mineral powders and water. Particles come in a wide range of sizes. Particles less than or equal to 10 micrometers in diameter are so small that they can get into the lungs, potentially causing serious health problems. Ten micrometers is less than the width of a single human hair [15], it´s shown in Fig. 1.

Coarse dust particles (PM10) are 2.5 to 10 micrometers in diameter. Sources include crushing or grinding operations and dust stirred up by vehicles on roads.

Fine particles (PM2.5) are 2.5 micrometers in diameter or smaller, and can only be seen with an electron microscope. Fine particles are produced from all types of combustion, including motor vehicles, power plants, residential wood burning, forest fires, agricultural burning, and some industrial processes.

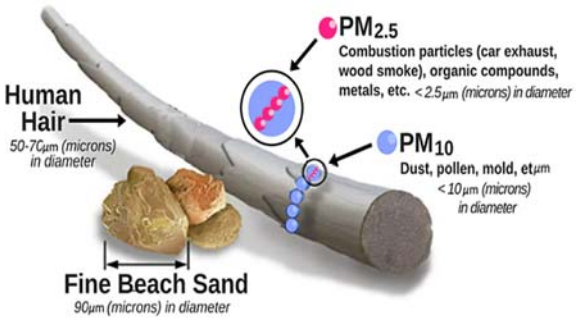


Fig. 1. Relative size of particulate matter [15].

Generally, air quality monitoring is implemented to determine PM10, although since 2008, WHO has also recommended that PM2.5 be measured in cities because they are the most harmful to health. In addition, in recent years the number of forest fires has increased, further aggravating the environmental situation.

2.4. Ammonia

Ammonia is a chemical substance usually used in refrigeration and fertilizer equipment, which is not

usually considered in the different official standards due to its small presence in natural conditions, being observed in high quantities only in industrial regions where substances are improperly handled or compounds related to this material, or, due to intensive agricultural and livestock activity, which promotes the release of greater than average amounts of fertilizer use [16]. This does not mean that its denomination as a contaminant is not of consideration, since its presence results in the generation of PM 2.5 suspended particles, usually known as aerosols [17]. On the other hand, its presence results in the acidification of soils and waters, which affects the development of vegetation and fauna [18]. Additionally, ammonia has the peculiarity that, when combined with other acidic contaminants such as SO_2 and NOx, ammonia (NH_3) becomes NH_4 +, which has a high diffusion range, extending several hundred kilometers from its point of origin (between 100 and 1000 km) [19]. The principal of ammonia concentrations shown in Fig. 2.

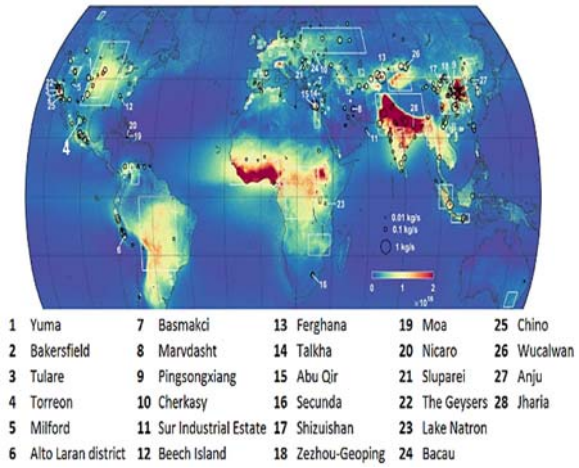


Fig. 2. Ammonia concentration map [13].

Ammonia can be a provider of an abundant amount of condensation nuclei in the form of ammonium nitrate (and ammonium sulphate) which, under favourable meteorological conditions, attract hygroscopic water, leading to rapid increase in the PM2.5 mass fraction [17]. The maximum limit allowed is 25 ppm.

2.5. Measurement Sensors

For the acquisition of data on the presence of gases in the air, the sensor by means of a resistance it is possible to obtain a dimensionless relation of resistances that determines the ppm of each element. The concentration of contaminating gases was determined by the relationship:

$$x = \frac{R_S}{R_O}, \qquad (1)$$

where x is the gas to be measured in ppm, R_s is the resistance of the sensor in Ω, Ro the adjustment resistance. R_o = 22 kΩ for NO_x and R_o = 45 kΩ for residual gases [20].

For the acquisition of data of suspended particles, an optical sensor measure particles over 1 μm and 2.5 μm in size. In order to get a reading, air passes through the bottom intake while the heating element (a resistor) heats the air, which forces particles to rise up and block the infrared light emitted by the IR LED which in turn provides a photodiode a signal in order to detect the variation in light levels which correlates to the presence of particles in the air. In optic system is necessary to provide a stable supply in this case 5 V, and sample time of at least 30 seconds, during which the microcontroller must measure the sum of all LOW signal periods in order to determine the concentration of particles in the air.

For the purposes of this project, was used calibrating equation in order to measure the concentration of particles in μg/m³ [21].

$$PM\,2.5 = 0.1809 \times (ratio)^2 + 3.8987 \times (ratio), \qquad (2)$$

where ratio is the amount of time the sensor signal was LOW. In order to get a better reading, an average over a longer period of time is advised in order to filter out any noisy readings.

3. Experimental

The mobile system for air quality monitoring uses emerging technologies such as UAV and WSN. The electronic instrumentation was integrated with high-range microdevices. A small wireless network of 2 nodes was implemented as an application example. An electronic control was implemented for the acquisition, storage, processing and transmission of data. It was integrated a Robust MEMS smart sensor node MiCS 4514 (SGX Sensortech, Switzerland) with capacity to detect up to 6 pollutant gases and a module optic sensor of suspended particles DSM 501A (Samyoung S&C, Korea). The electronic control can communicate up to a distance of 750 m. between nodes and towards the base station by a PC. A storage system to protect acquired data was integrated, it shown in Fig. 3.

The electronic control was mounted in each UAV, making the mobile monitoring system an autonomous device. A small UAV (drone) Spark dji was used (dgi, USA). For the support of electronic control, a structure in PLA material was manufactured using a desktop 3D printer (FlashForge Creator Pro, China) as shown in Fig. 4.

The acquired data is transmitted through RF modules to a computer, where a graphical interface processes and shows in real time the concentration of contaminating gases in ppm. The graphical interface was programmed in LabVIEW and it is show in Fig. 5.

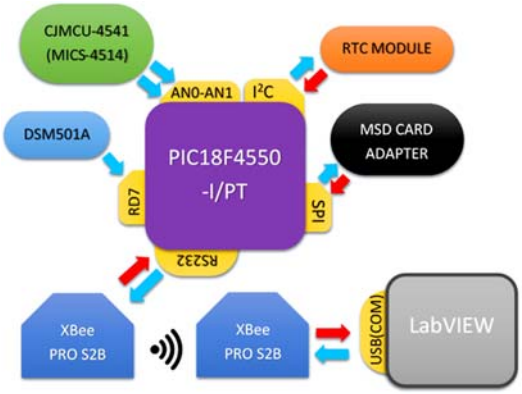


Fig. 3. Experimental set-up.



Fig. 4. UAV and PLA structure.

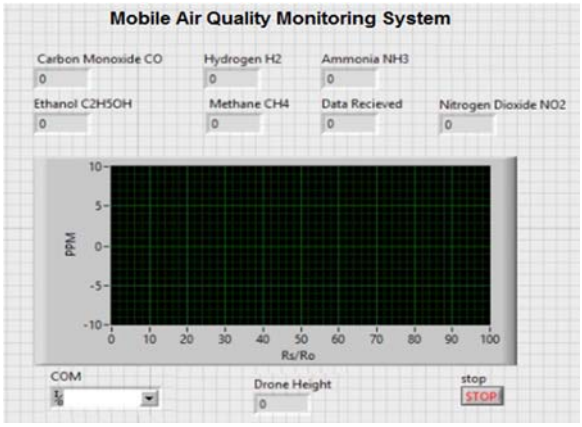


Fig. 5. Graphical interface for Mobile Air Quality Monitoring System.

The interface has other characteristics such as regionalization, organization and storage of files and reading of files obtained from memories of the devices.

4. Results and Discussion

For the measurement in the environment, tests were carried out in 6 different points according to the graph shown in the Fig. 6.

In order to validate the operation of the Monitoring System, controlled tests were made to measure PM2.5. The first test was done in point 3 Fig. 6.



Fig. 6. Location of monitoring points.

The sample was taken in the pruning process of the football field which contained allergen, pollen and dust. The second test was done in point 6 an enclosed area. The sample was taken in welding process which generated welding steam containing lead, tin, bismuth. The results are shown in Fig. 7 and Fig. 8 respectively.

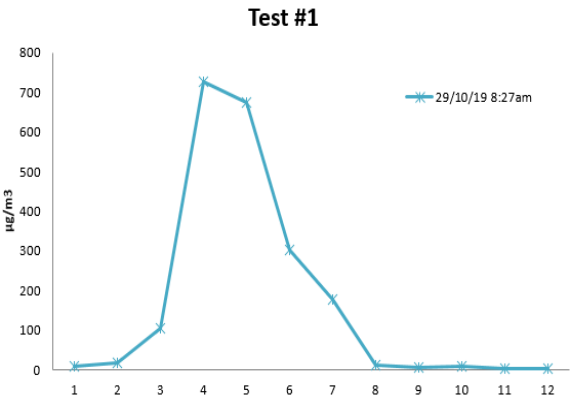


Fig. 7. Response graph to allergens, pollen and dust.

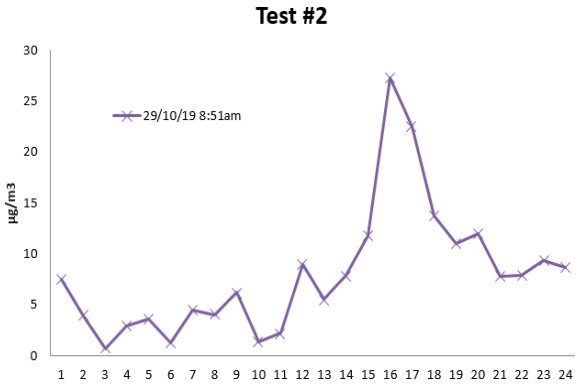


Fig. 8. Response graph to welding steam.

The process of measurement in the environment, consisted of 12 readings, each taking 30 seconds to complete. Afterwards, any measurement determined to be inaccurate (it deviated a considerable amount from the measurements expected outdoors) was eliminated from the chart. Any measurement above 100 µg/m³ was omitted. The results are shown in Fig. 9 to Fig. 14.

The calibration was presented in previous work and show four critical pollutants including ammonia, in order to characterize the gas sensor [20].

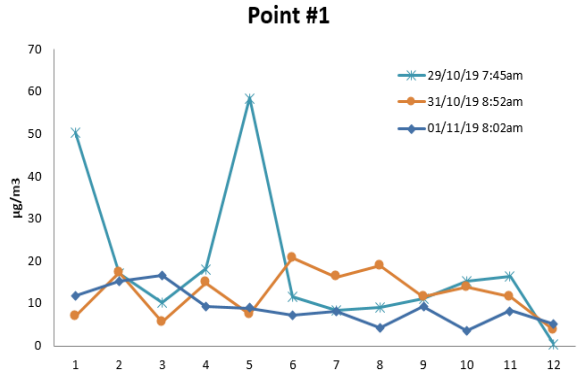


Fig. 9. Response graph 3 days in point 1.

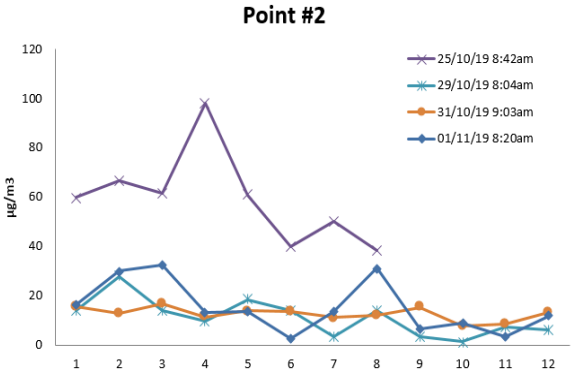


Fig. 10. Response graph 3 days in point 2.

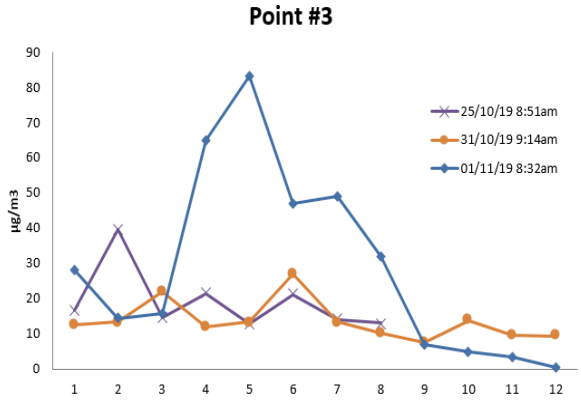


Fig. 11. Response graph 3 days in point 3.

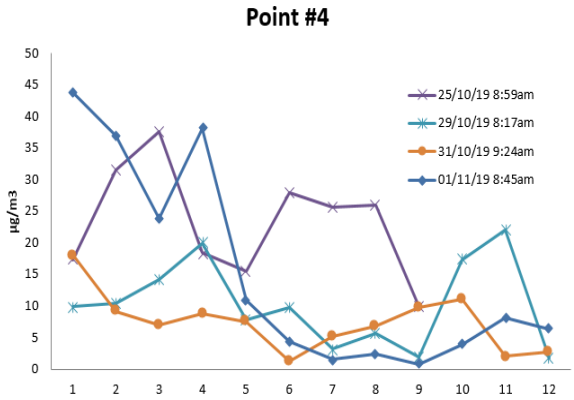


Fig. 12. Response graph 3 days in point 4.

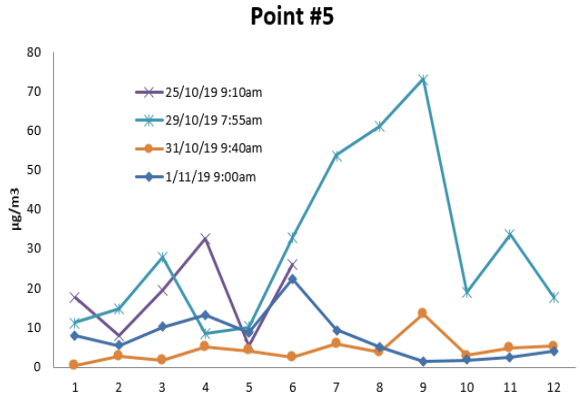


Fig. 13. Response graph 3 days in point 5.

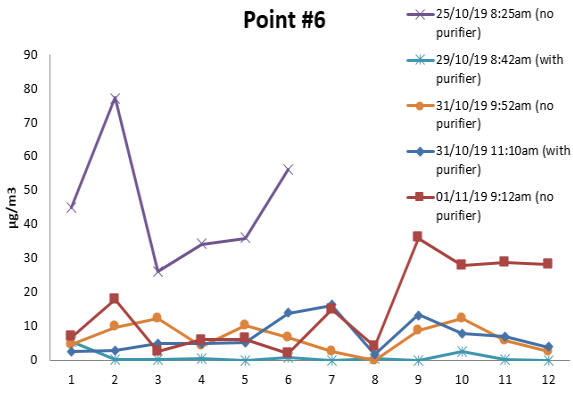


Fig. 14. Response graph 3 days in point 6.

Other measuring were made to evaluate the presence of gases mainly CO_2, NO_2 and NH_3 in outdoor environment. The response of air quality monitoring system are show in Fig. 15 to Fig. 20.

Environmental tests of air quality were performed in Torreon, Coah., Mexico. Figs. 21-22 show the aerial view of city. The system was probed to measure traffic pollution at peak hours and industrial operations at 100 % (13:00 hrs) at a flight height of 15 to 30 meters.

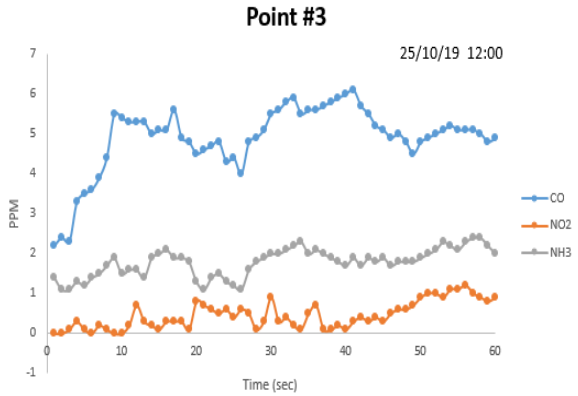


Fig. 15. Response graph in point 3.

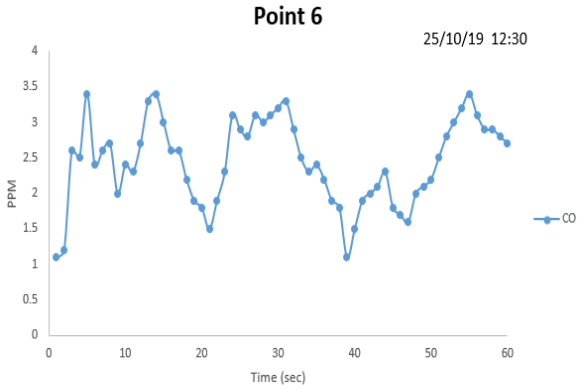


Fig. 16. Response graph in point 6.

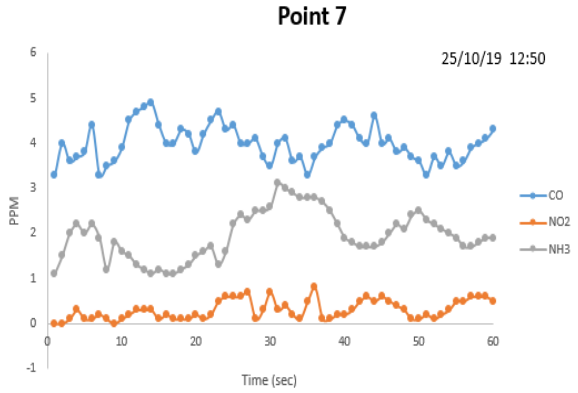


Fig. 17. Response graph in point 7.

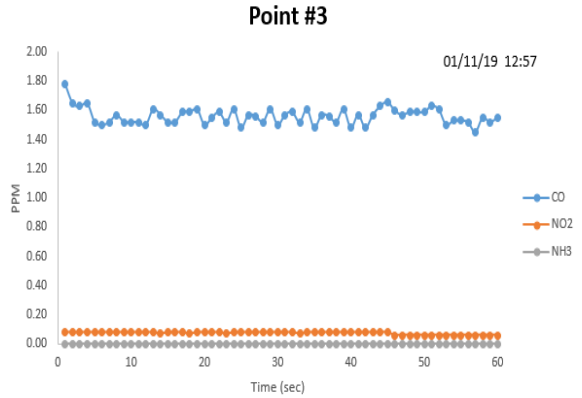


Fig. 18. Response graph in point 3.

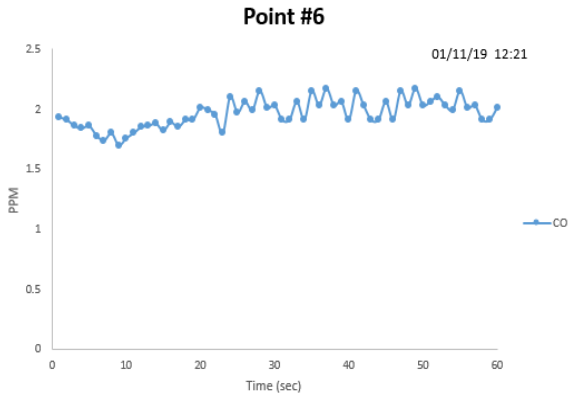


Fig. 19. Response graph in point 6.

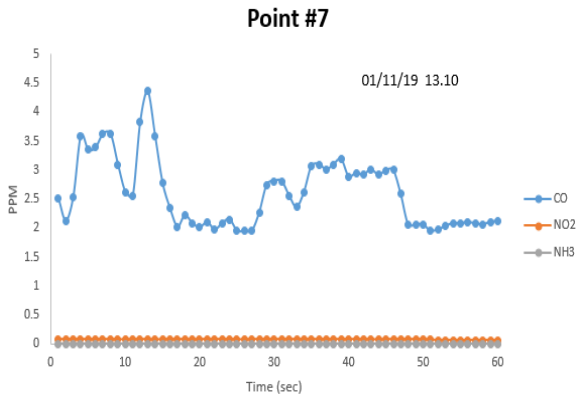


Fig. 20. Response graph in point 7.

According to the SMN (national meteorological system) of the CONAGUA, there are four monitoring stations in Torreon, 5006, 5026, 5029 and 5040, of which only one operates and located in the La Flor dam (5029). In addition, as critical data, the records history of environmental measurements are not updated, they only report to 2010.

Due to the above, until the dates reported in this work were not validated with official records. It is important to have updated, truthful and timely information in real time on air pollution rates, as it has been shown that Torreon is among the specific emitters of atmospheric ammonia. The work presented here, is a step to the initiative for the conservation of

the environment and generate information for the prevention of diseases caused by poor air quality.



Fig. 21. Torreon aerial view early in the morning.



Fig. 22. Torreon midday aerial view.

Children, people over 65, pregnant women and people with heart or lung diseases (including asthma) are more sensitive to the effects of breathing these particles. Symptoms may include wheezing - acute wheezing through the respiratory ducts - chest tightness and shortness of breath.

In addition, high levels of PM 2.5 also cause irritation to the eyes, nose and throat; cough, chest tightness and trouble breathing; reduced lung function; asthma attacks; heart attacks and premature death in people with heart and lung diseases.

5. Conclusions

A wireless distributed mobile air pollution monitoring system was designed, implemented and tested using the UAV and WSN. The system measured concentration of pollutant gases such as CO, NO_2, NH_3 and PM2.5. The pollution data from various mobile sensor arrays is transmitted to a central server in PC and storing data in a micro-sd memorycard. The data shows the pollutant levels and should be considered by the local air quality regulatory.

The system is based in MICS-4514 sensor and it is focused on the detection of residual gases (RED) and nitrogen gases (NOX). It is mainly dedicated to CO and NO_2, but it is also capable of detecting ammonia, propagation, ethanol, hydrogen and H_2S values with certain limits.

On the other hand, the System also has the ability to detect PM2.5, obtaining a high sensitivity of response both in laboratory experimentation and environmental tests.

In this short sampling it was found that if there is NO_2 in the air, the presence of NH3 and the increase in PM2.5 are also shown.

A lot of work is required to complete a robust system. We recommend more tests to be done for a solid conclusion about the pollution of ammonia.

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