Methane emission measurement wireless system for monitoring air pollution close to Chilla-Juliaca landfill

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***Abstract— Abstract—* In many countries, most organic waste is usually placed in landfills, which generates public concern about the health effects of emissions pollutants. The natural bacterial decomposition of organic waste produces landfill gases, about half of the methane, with the remainder mainly carbon dioxide and minor amounts of other gases. Real-time measurement and modeling of emissions gases in landfills are essential. This work develops a low-cost wireless measurement system using MOS gas sensors (MQ4, MQ5, and MQ9), a 32 bits microcontroller, an XBee module, and HC-12 wireless communications modules. The system can be mounted on an uncrewed aerial vehicle (UAV, drone) or deployed as a wireless sensor network. Experiments have been carried out near a closed landfill, and measurement results show high methane concentrations.**

Keywords—landfill gases, methane, dioxide, real-time measurement

I. Introduction

We generate millions of tons of solid waste daily, which will increase because the population and many economies are also growing continuously. Landfills are filled quickly, generating tremendous environmental pollution because they release methane (CH4), carbon dioxide (CO2), and other greenhouse gases, which can harm the health of the exposed population [1]. Understanding and measuring these kinds of gases is essential to inform people living close to landfills and the corresponding authorities that should take environmental protection policies.

Peru is an upper-middle-income country with stable economic growth in recent years. As a result of the growing middle class, massive urbanization and high consumption habits increase domestic solid waste. Municipal solid waste is dumped in unmanaged landfills without adequate treatment, and organic solid waste decomposition can cause health and environmental problems because of air pollution [2].

Significant differences exist between developed and developing countries in solid waste generation, management, and reusing policies [3]. In Sweden, a named developed country, the number of closed landfills containing organic waste is estimated to be between 4000 and 8000. Most of them were established during the last 100 years, thus still within their methane and CO2-producing phase, which is expected to be 100 years. To mitigate pollution originating from landfills, Sweden prohibited the deposition of organic waste in 2005 [4]. In developing countries like Peru, it will take many years to make similar decisions.

Recently the authors in [5] have presented an estimation of the methane generation rate in a landfill site which was computed as 0.012 per year and the methane generation capacity as 54.26 m3 /Mg. The authors have yet to find much written about the measurement of gases emitted in landfills; however, these measurements were performed with some value approximation when measuring greenhouse gases. Laser-based sensors for horizontal and vertical profiling of greenhouse gas levels in the atmosphere, including an auto-aligning, are presented in [6] as a system that can monitor gas emissions in landfills. Polese et al. [7] have developed wireless sensor networks for greenhouse monitoring, using commercial and ad hoc devices as layered double hydroxide sensors; this system can monitor CO2, NOX, and other gases present in the greenhouse together; and also measure humidity temperature and light intensity. Fieldwork was carried out to measure the effect of reducing irrigation levels and its correlation with GHG emissions from soil and crop yield on maize cultivated in the Tuscany region (Italy) [8]. This Monitoring process used a transportable instrument developed by West Systems, equipped with two detectors, one for CO2 and CH4 and the other for N2O.

As we see from the above studies, greenhouse gas sensors and measurement methods are necessary and should be considered. With the rapid development of electronics, new and cheap gas sensors can be found in the market. WSN technology can be used as a measurement method but should be inexpensive and easy to install.

We have developed a low-cost wireless measurement system to measure Carbon Dioxide (CO2) and Methane (CH4) using MOS sensors (MQ4, MQ5, and MQ9), microcontroller, and XBee wireless communication modules; the interface to the computer is coded in Python and the embedded firmware in Arduino C. The system could be deployed as a wireless sensor network or mounted over an uncrewed aerial vehicle (UAV, drone).

Data Transmission uses the industrial, scientific and biomedical (ISM) radio frequency band transmission at 2.4GHz and the Ultra high frequency (UHF) radio frequency at 433.4MHz, both RF bands are free to hobbyist and wireless application.

This paper has the following sections. Section 2 describes the methods and materials used and describes the measurement setup. Section 3 introduces the measurement results and analysis. Finally, Section 4 presents our conclusions.

II. Materials and Methods

The development of the gas emission measurement system for Chilla-Juliaca is described with these four steps:

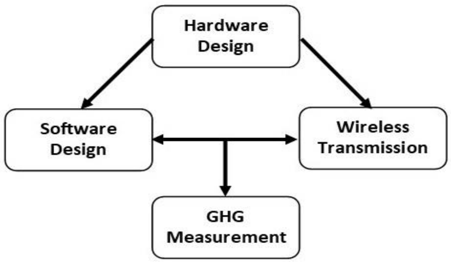

Fig. 1. Measurement System block diagram

A. Hardware design

Figure 1 shows the designed circuit that controls four sensors (MQ4-1, MQ4-2, MQ5, and MQ9); the sensor generates a change in their internal resistance while gas is detected, and a proportional voltage drops in the load resistor (RL) that measure the analog gas output signal. The system uses a 16-bit analog-to-digital converter (ADC) embedded in the ADS1115 module that receives the response of every gas sensor with a compact and versatile I2C serial communication protocol. Previously, signal conditioning for suitable data acquisition processing was necessary using an operational amplifier LM358.

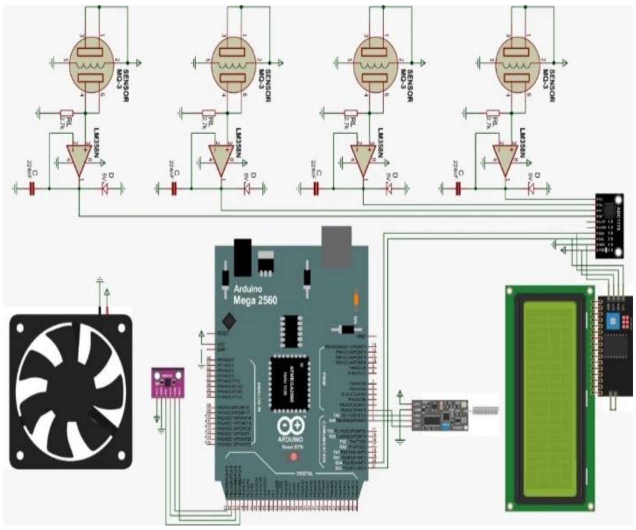

Fig. 2 Wireless Measurement system hardware with embedded modules

Data acquisition with ADS1115 module drives 15 bits of resolution, which means that the sensibility of the signal is precise, and we calculate the voltage signal as shown in (1); it represents a resolutión with a minimum value of 0.15mV; this gives us the option of measure tiny variations of the detected gas signal.

$$Vadc = \frac{V_{+} - V_{-}}{2^{15}} = \frac{5-0}{32768} = 0.15mV \quad (1)$$

B. Wireless Transmission

Wireless transmission use HC-12 RF modules that can reach up to 1000m, and the same distance can reach the Xbee modules. Both cases use remote modules as end devices and a coordinator to control the data transfer and achieve good network transactions. The coordinator is always linked to the web server, see Fig. 3.

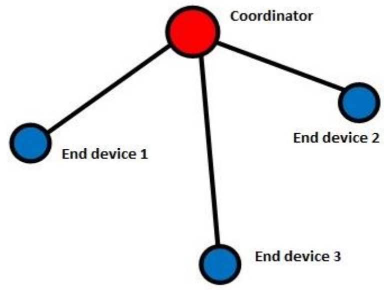

Fig. 3. WSN star topology

To Configure the HC-12 RF modules, we use AT commands to achieve excellent wireless data transmission; in our case, the module is setup to reach up to 600m long distance, 9600bps data transmission speed, 433.4MHz frequency transmission, data transfer can use all channels from CH001 to CH100 in a multiplexed way to support all sensors connected as endpoints remotely; also power configuration ensure long-distance transmission, in our case 100mW is set up to reach up to 1000m, AT commands are shown here:

AT+FU3 (max long distance 600m)
AT+9600 (9600bps, 8 dibit data, no check, one stop bit)
AT+C001 (CH001 433.4MHz).
AT+P8 (20dBm, 100mW)

As a second option to transfer wireless data, we have evaluated three different DIGI XBee modules: XBee 802.15.4, XBee S2C ZigBee, and XBee S3B DigiMesh. The modules used in this work use the technical standard IEEE 802.15.4, which defines the operation of a low-rate wireless personal area network. This standard is designed for energy-efficient communications in a point-to-point configuration and includes sleeping and security.

We have designed and implemented 3 modules that can be used to form a WSN. Figure 4 shows a finished module.

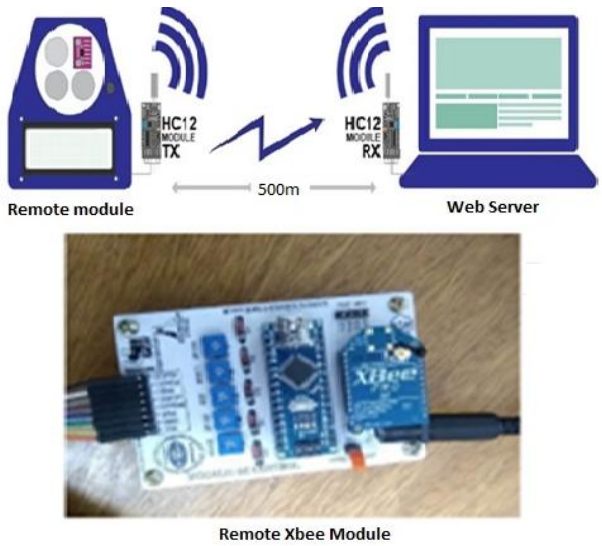

Fig. 4. Wireless monitoring with RF modules

C. *Software design*

The software developed integrates two modules: the first is coded in Arduino-C and supports the firmware program necessary for every microcontroller that governs the system hardware. The second module is coded entirely in Python because of its versatility and the great advantage of its open-source coding philosophy; also, we recognize the vast number of libraries to improve data processing and graph plotting with matplotlib tools. The communication interface algorithm is also designed in Python to transfer real-time serial data between endpoints modules and the coordinator linked to the web server computer at 115200bps; finally, data encryption is also implemented to minimize data loss in transmission. The algorithm to wireless data transmission is as follow:

1.- Read analogue signal from sensor

2.- Convert analog to digital signal

3.- Find ppm value with general equation (2)

4.- Open serial transmission

5.- If serial open

Send start bit

Send data frame

Send stop bit

6.- Goto 1

D. *Air pollution measurements in Juliaca city*

Juliaca city is one of the largest cities in Peru with an estimated population of more than 256,093 habitants, with a domestic solid waste of 0.70Kg/hab/day, and 1.0Kg of municipal solid waste percapita in a day. The calculation report an accumulation of 240.60 tons/day and 87,817.70 tons/day according to report given by environmental ministery. The organic solid waste is 48.466.30 tons/day, and only 3% is reused to produce compost; for that reason, nowadays, Juliaca City has serious environmental pollution problem because people cannot handle the garbage properly and municipal solid waste managemente is deplorable. This indicator gives reasons to hypothesize that CH4 and CO2 emissions are increasing in downtown especially in Chilla landfill that is rounded by population.

E. *Monitoring air Pollution with MOS sensors*

To monitor traces of methane and carbon dioxide in Juliaca city and close to Chilla landfill, we must find the general equations to measure methane and carbon dioxide, these equations should have a relationship with the concentration of methane or carbon dioxide in ppm.

The general equation we use to find a particular gas is shown in (2)

$$ppm(gas) = k.\left[\frac{RL}{Ro}.\left(\frac{V_{cc}}{V_{adc}} - 1\right)\right].1^{\frac{1}{m}} \quad (2)$$

Now applying (2) we obtain equations (3) and (4) using a computational program because of complexity calculation of the slope (m).

Find the equations for MQ4 and MQ5 sensors for detecting methane will have different slope value and therefore different equations dependants of their own responses and sensibility to methane, because sensors not respond the same at methane detection.

Methane- MQ5

$$ppm(ch4) = 152.4(\frac{2.2}{2.1}\left(\frac{4.8}{VADC} - 1\right))^{-2.71} \quad (3)$$

Methane- MQ4

$$ppm(ch4) = 1000(\frac{2.2}{1.22}\left(\frac{4.73}{VADC} - 1\right))^{-2.807} \quad (4)$$

Emissions of methane were monitored in six places of Juliaca cyty, methane concentration is going up to 3ppm in places with high concentration of cars and population, but in places outside of the city, the concentration of methane is under 2ppm. Concentration of carbon dioxide as shown in Fig. 5 is higher in central public market, methane goes up to 700ppm and the lower concentration is located in the university with an average of 400ppm

- Trade center (A)
- Huaynaroque mountain (B)
- Downtown street (C)
- Central Public Market (D)
- Main square (E)
- Andina University (F)

Figure 5. shown distance between trade center and all points of monitoring.

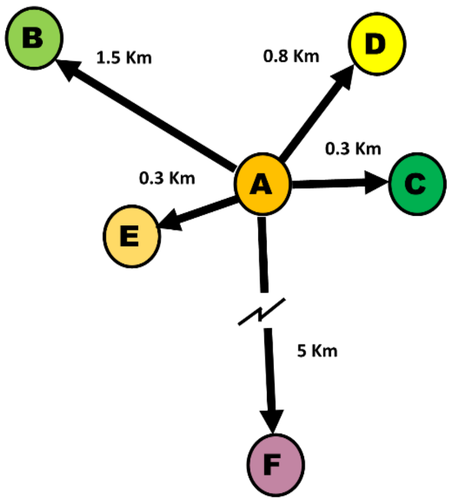

Fig. 5. Comparative distances in monitoring points

The election of six points was defined to differentiate the measurements of gas emission between the center of the city and places far away from downtown.

III. MEASUREMENTS RESULTS

As a first step, measurements were carried out on six monitoring points of Juliaca city, where points A, E, and C are in the central city; the public marketplace is represented by D point at 0.8Km, a well-known "Huayna Roque" mountain far away to 1.5Km is represented by B point; finally, the university campus located far away to the central city at 5Km is represented by F point. Comparative results of CH4 and CO2 measurements with the sensor module were performed with equations (3) and (4) to detect methane and another one to CO2, which are shown in Figure 6.

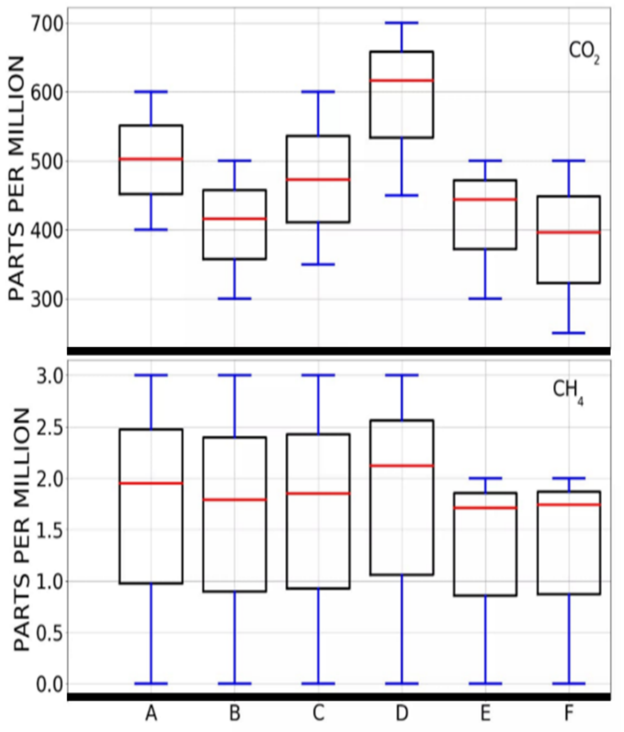

Fig. 6. Comparative results of CH4 and CO2 in Juliaca city

We can interpret the CO2 emission in poins A,C and D as high considering that this points are in downtown, but especially the point D represent the public market, and in this place traffic congestion is high, and therefore CO2 amission is obviously high too. Points B and F have low CO2 emission because B represent a mountain far from downtown and F represents the universisity 5Km far from downtown, that is the reason for a low CO2 emission of 400ppm that represent the concentration in clean air.

About methane emission the interpretation depends of the garbage acumulation, in this case the points A,B and C have low methane emissions with a mean of 2ppm, the point D represent the public market and it round 3ppm; point E is the main square, and poit F the university far from downtown and for that reason have low level with 1.8ppm that represent the concentration of methane in clean air.

A. Air pollution measurements in Chilla-Juliaca Landfill

In recent years, Juliaca population has increased considerably, which has generated uncontrolled increase of solid waste as consequence. More than 90% of the total waste generated daily by the population of Juliaca is deposited in the Chilla-Juliaca landfill [9].

According to the OEFA [10], more than ten landfills in Peru do not meet the appropriate conditions for their operation; among them is the Chilla-Juliaca landfill. The situation worsens since more than 900 families are settled around the dump, risking their health.

Chilla – Juliaca landfill keeps tons of municipal solid waste; it is not well-engineered and is now closed because of population claims; its nearest location caused many respiratory diseases, especially due to environmental pollution due to malodor emission of landfill.

In Figure 7 we can see Chilla Landfill rounded by a red circle near to the population, this zone should not be habitable, but increse population and the needed of a place to living forced to population to choose this place to live near the Chilla landfill, also they have municipal water and electric fluid and downtown is about 5Km.

Fig. 7. Location of Chilla-Landfill.

There were important aspects that aggravated this problem, name one, the periodic incineration of waste have been generated the production of all types of toxic pollutants that causes many respiratory and skin diseases [11]. Given this situation, the authorities decided to close the landfill according to the following plan: 4 cells would be built, cover the solid wastes with soil, chimney installation, and leachate drains building. This procedure has reduced toxic emissions but has not been eliminated completely because despite the landfill being closed, toxic gases are still emitted, causing discomfort to the nearby population.

Figure 8 shows the representation of the Chilla landfill closed completely under soil because the landfill got a limit of filling municipal solid waste. Also, we can see that the landfill has many pipes to liberate gases and avoid methane concentration under pressure; however, these emissions produce pollutants in clean air, and contamination goes forward within a radius of 1 km in less than three seconds if we consider that molecule methane velocity is about 640m/s and, H2S is about 466m/s. Other factor to increase velocity transmission with pollutants is the wind velocity that in Juliaca has a media of 3.6m/s in a normal day.

As a second step methane measurements over the closed Chilla landfill were performed in different points of the mountain. As we see in Fig 8 the Chilla landfill has many pipes to liberate gas pressure, and methane with other toxic pollutants are expulsed by the pipes; contributing with the malodour around the population in a radius of 1Km.

Fig. 8. Chilla Landfill representation

Calibration of the sensors with the standard concentration of methane in clean air was performed to get a good approximation of methane measurements. To obtain the equation (2) the following procedure was done: firstly, voltage in clean air was measured of every sensor, in this procedure MQ4 give out approximately 0.8v, and MQ5 0.9v. Therefore the correlation of both voltage sensors was set up in 2ppm, considering that the standard value is 1.9 ppm in 2022 according to the monitoring information of NOAA observatory shown in Fig. 9

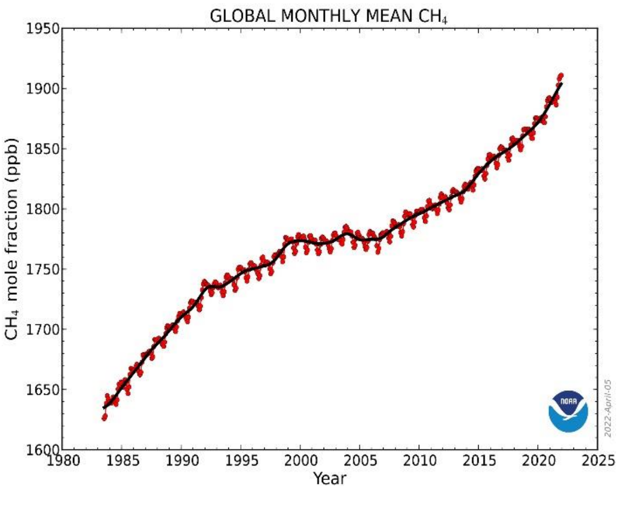

Fig. 9 Global mean Methane

The results measured in downtown are in the range of NOAA observatory, because we have obtained from 2 to 3 ppm values, however the results in Chilla landfill have high values as we can see in the following analysis of our results.

Now the results of monitoring gas emission with our measurement system using MOS sensors in Chilla-Juliaca landfill was done in two different places as shown in Fig. 10, the methane emission on the drainage and Fig. 11 show us the methane emission of the swarm.

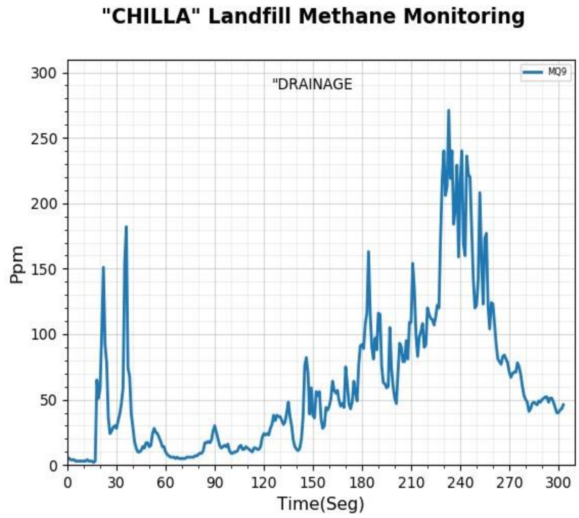

Fig. 10. CH4 monitoring in drainage place.

In this case Fig. 10 show us the methane emission in drainage, and we can see that the response is extremely variable and depends of different factor as the air steam, wind address or the temperature variation. We have observed in the same place the generation of bubbling water over the soil like it was boiling because of methane emission conversion to water and carbon dioxide. We could also observe that the malodour was supportable and provoke us headache and eye irritation, we could not stay no longer than a half hour.

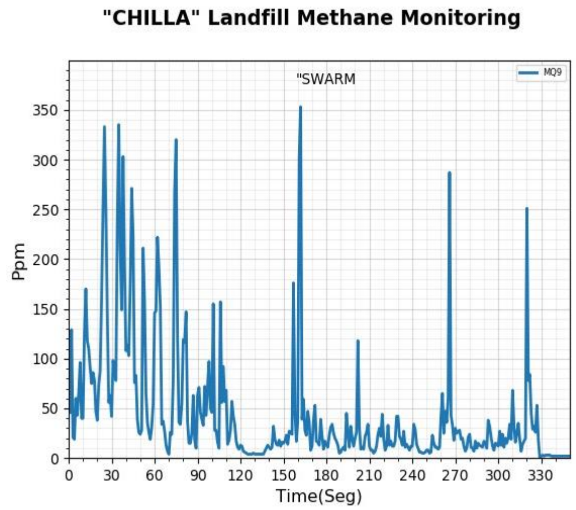

Fig. 11. CH4 monitoring in swarm place.

In this case we could observe that the methane emission from the pipes over the soil expulse the methane with high pressure, it means that exist high activity in decomposition of organic solid waste. These pipes have an height of 2.5m and the methane expulsed follow the wind direction and the malodour comes with great facility to the population around.

IV. Conclusions

In this work, we have designed cheap modules to measure polluting gases, specifically Methane using MOS gas sensors, but CO2 also was measured. The principal goal was to determine the methane emission in the closed Chilla landfill to alert how hazardous is to near population living there.

Calibration MOS sensors were the primary objective to detect gas measurements in the ppm range, and all of them were performed with great accuracy obtaining the equations that brings in real time the concentrations of methane or carbon dioxide in ppm

The wireless transmission was coded in the firmware of the microcontroller and get a clean data transmission using XBee and HC-12 modules in the form of coordinator and end devices to monitor the methane emission over the landfill.

Our modules have been calibrated firstly in clean air and the response of measurements obtained in downtown and in Chilla landfill gave us acceptable results with a mean of 2.5 ppm in downtown and 300ppm over the landfill.

We are not taking advantage of methane generation in landfills; we suggest that our rules change the policies of solid waste management to prevent environmental pollution and health risk in the population around landfills.

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