Monitoring Metropolitan City Air-quality Using Wireless Sensor Nodes based on ARDUINO and XBEE

Ali Al-Dahoud, Mohamed Fezari, Ismail Jannoud and Thamer AL-Rawashdeh

Abstract—Wireless sensor networks (WSN) have been experimented in different applications including monitoring many environmental phenomena such as air quality assessment, forest fire monitoring, flood rivers control during last decade. In this paper, we propose an architecture node and a simulation interface for WSN in monitoring air quality in metropolitan cities. Nodes are equipped with gas, temperature and dust sensors, an Arduino-uno as microcontroller have been designed for air quality monitoring in some sensible area at Annaba City East of Algeria. The new design is based on Arduino-uno as microcontroller.

Comparing sensed gas from three different regions in the city to normal gas levels (for the clean air), the obtained results from the several tests and acquired data, indicate that there is a big difference in the gas levels of both gases (LPG, NO2 and CO). However, the acquired results for the air quality control in some areas in Annaba city show no risky situation to be considered for further actions. In this work we cover the field of Air-quality monitoring electronic Nodes design and wireless transmission of fusion data. Then A GUI has been designed for simulation of the WSN in controlling the environment air Quality. Tests are encouraging; the flexibility , the presence of components and the ease of design facilitates the implementation of this system.

Keywords—AQM, Arduino-Uno, wireless sensors network, air quality in city.

I. Introduction

AIR pollution can affect many body organs and systems in addition to environment based on report of World Health Organization (WHO), air pollution is significant risk factor for multiple health conditions including: heart disease, lung cancer, pneumonia, difficulty in breathing and coughing due to aggravated asthma [3] .Wireless Sensor Networks (WSNs) technology [4] and [5] is in the front part of the investigation of the computer networks and it could be the next technologic market of with huge sum of money in investment. Sensor nodes can be fixed or mobile, they have limited processing power, storage, bandwidth, limited wireless transmission range and energy powered by battery. This limitation makes provision of the security in sensor networks not an easy task [4]. The availability of cheap, low power, and miniature embedded processors, radios, sensors, and actuators, often integrated on a single chip, is leading to the use of wireless communications and computing for interacting with the physical world in applications such as air quality control.

In Fact, with the increasing number of vehicles on our roads and rapid urbanization air pollution has considerably increased in the last decades in Annaba city (Algeria). For the past twenty years the economic development of this city has been based on industrial activities and the agriculture industry. Hence, there has been the growth of industries and infrastructure works over the island. Industrial combustion processes and stone crushing plants had contributed to the deterioration of the quality of the air.

In this paper, we propose to use a WSN based microcontroller equipped with gas sensors have been actively used for air quality monitoring. The design included several units mainly: Arduino Microcontroller, MQ-2 Gas Sensors, and the current regulator circuit the paper is organized as follow: in second paragraph after introduction we define primary pollutants, in paragraph 3, we present the hardware proposition design with main components. In section 4, format and communication with the special sensor DHT11 is illustrated, then we conclude the paper by presenting results, discussion of simulation in section 5, finally conclusion and perspectives were included in section6.

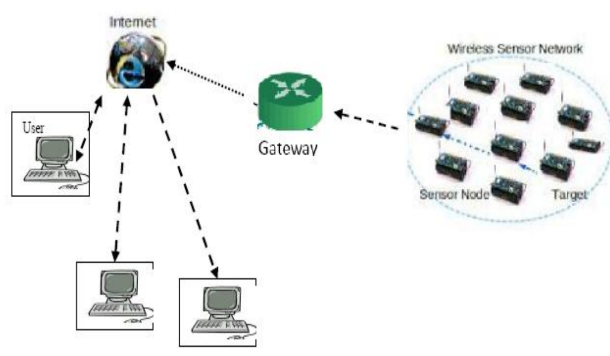

Figure 1: The Hardware Design Schematic Diagram.

II. Primary Air Quality Pollutants

Primary pollutants are those in which the substance emitted is itself hazardous. Some primary pollutants also produce other dangerous substances after undergoing chemical reactions in the atmosphere, and these are known as secondary

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pollutants. Primary pollutants include the following substances as mentioned in [15].

Particulates : This includes dust, smoke, aerosols and haze - any finely divided airborne solid material. Particulates are commonly generated by fires, motor vehicles, some industries (particularly road building, quarries and fossil fuel power stations) and various natural sources including volcanoes, plant and animal matter and dirt. Particulates are aesthetically displeasing, can irritate the eyes and cause respiratory problems. In recent years concerns have been raised about the possible health effects of 'fine' particulate matter (less than 10µm diameter). These have been shown to be associated with increases in hospitalization and even deaths from respiratory illnesses and heart disease.

Sulphur dioxide, SO2 : Sulphur dioxide is often produced by the industrial processes which produce particulates, the primary sources of SO2 being coal, fuel oil and diesel. Being a corrosive acidic gas, sulphur dioxide damages buildings and other materials, and can cause respiratory problems.

Carbon monoxide, CO : The commonest source of carbon monoxide is motor vehicle emissions, where it results from the combustion of petrol in the presence of insufficient oxygen. It is also a result of some fuel-consuming industries and domestic fires. Carbon monoxide is a color less, odorless, highly toxic gas that displaces oxygen in human blood, causing oxygen deprivation.

The oxides of nitrogen, NOx : NOx refers to the mixture of nitric oxide (NO) and nitrogen dioxide (NO2) formed by the oxidation of nitrogen during the combustion of air. The majority of NOx is produced in motor vehicle emissions, although other sources can have significant local impact. NOx is a contributor to several secondary pollutants, and NO2 is a respiratory irritant that can also corrode metals at high concentrations.

Benzene : Over the last few years leaded petrol have been phased out of use. However this has resulted in higher levels of benzene and other aromatics in the substitute unleaded petrol. Benzene breaks down quickly in the environment and is not stored in the tissues of plants or animals. However, it is still hazardous to humans at high levels as it can cause several diseases of the blood including leukemia (cancer of the white blood cells). Benzene monitoring programs were started in New Zealand in 1994 and are continuing because the levels in some locations were found to be reasonably high.

Hydrogen sulphide, H2S : Hydrogen sulphide is mainly associated with geothermal activity, where it is responsible for the 'rotten eggs' smell, but it is also formed from the anaerobic decomposition of many organic wastes and is a by-product of paper manufacture and leather tanning (see article). It is highly poisonous (more toxic than hydrogen cyanide), and because it initially anaesthetizes the sensory organs it can build up to high concentrations without warning and cause paralysis and then asphyxiation.

Fluorides: These have two main sources: the Comalco aluminium smelter and fertilizer works . Fluorides can have adverse effects on plants and in some cases concentrate in the leaves so that animals eating the plants ingest significant quantities.

II. PROPOSED AIR MONITORING SYSTEM DESIGN

The complete system design is shown in figure 2, Hardware Design Schematic Diagram. The design

Included the following major hardware components:

A) . Arduino Microcontroller [1]: this is the core component of the design. Arduino is a flexible programmable hardware platform designed for fast Embedded Systems platform conception. Arduino's little, blue circuit board, mythically taking its name from a local pub in Italy, has in a very short time motivated a new generation of microcontroller users of all ages to make all manner of wild projects found anywhere from the hallowed grounds of our universities to the scorching desert sands of a particularly infamous yearly arts festival and just about everywhere in between.

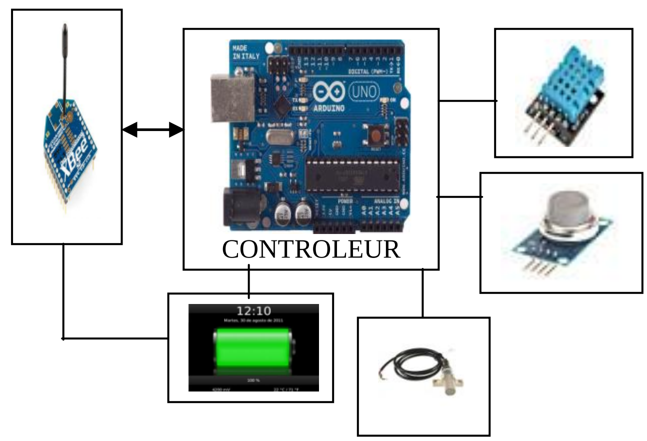

Figure 2: Sensor Node main Components

Usually these Arduino-based projects require little to no programming skills or knowledge of electronics theory, and more often than not, this handiness is simply picked up along the way.

In figure 2.b we can see the main components in the arduino-uno system board.

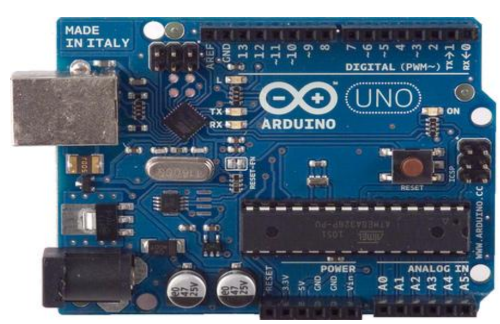

Figure 2.b: Arduino-uno system board

B). MQ-2 GAS Senor [17: MQ-2 Sensor is used in gas leakage detecting equipments in family and industry, are suitable for detecting of LPG, i-butane, propane, methane ,alcohol, Hydrogen, smoke.

Resistance value of MQ-2 is difference to various kinds and various concentration gases. So, When using this components, sensitivity adjustment is very necessary. we recommend that you calibrate the detector for 1000ppm liquefied petroleum gas<LPG>,or 1000ppm iso-butane<i-C4H10>concentration in air and use value of Load resistance that(RL) about 20 KΩ(5KΩ to 47 KΩ).

This sensor module utilizes an MQ-2 as the sensitive component and has a protection resistor and an adjustable resistor on board. The MQ-2 gas sensor is sensitive to LPG, i-butane, propane, methane, alcohol, Hydrogen and smoke. It could be used in gas leakage detecting equipments in family and industry. The resistance of the sensitive component changes as the concentration of the target gas changes.

C) Temperature and Humidity sensor

The DHT11, DHT21 and DHT22 are relative cheap sensors for measuring temperature and humidity. In reference [6] and [7] there is a description of library for reading both values from these sensors. we contacted the manufacturer to get the details of the differences between the two DHT sensors to build a lib that supports both. The DHT21/22 is quite similar to the DHT11 and has a greater accuracy (one decimal) and range (negative temperatures), however the price of DHT11 is lower. The hardware pins and handshake are identical but they use different data formats.

Communication and format for DHT11 : Single-bus data format is used for communication and synchronization between MCU and DHT11 sensor. One communication process is about 4ms.
Data consists of decimal and integral parts. A complete data transmission is **40bit**, and the sensor sends **higher data bit** first.

Data format: 8bit integral RH (Relative Humidity) data + 8bit decimal RH data + 8bit integral T data + 8bit decimal T data + 8bit check sum. If the data transmission is right, the check-sum should be the last 8bit of "8bit integral RH data + 8bit decimal RH data + 8bit integral T data + 8bit decimal T data".

D) Resistance Circuitry: Resistance value of MQ-2 is difference to various kinds and various concentration gases. So, When using this components, sensitivity adjustment is very necessary. we recommend that you calibrate the detector for 1000 ppm liquified petroleum gas <LPG>,or 1000 ppm iso-butane<i-C4H10>concentration in air and use value of Load resistance that(RL) about 20 KΩ (5KΩ to 47 KΩ).

E) Xbee Trasmission module: is based on Zigbee protocol: The XBee radios can all be used with the minimum four number of connections – power (3.3 V), ground, data in and data out (UART), with other recommended lines being Reset and Sleep [18]. Additionally, most XBee families have some other flow control, I/O, A/D and indicator lines built in. A version of the XBees called the programmable XBee has an additional onboard processor for user's code.

Figure 2.c: Transmission Module Xbee

IV. DHT11 Sensor programming and protocol

Source code for DHT11 sensor reading by Arduino uno**:** in there code lines we illustrate part of the software to be included into the arduino uno memory.

```
#include "dht.h"
int dht::read11(uint8_t pin)
{
   // READ VALUES
   int rv = read(pin, DHTLIB_DHT11_WAKEUP);
   if (rv != DHTLIB_OK)
   {
      humidity    = DHTLIB_INVALID_VALUE; // invalid value, or is NaN
prefered?
      temperature = DHTLIB_INVALID_VALUE; // invalid value
      return rv;
   }

   // CONVERT AND STORE
   humidity    = bits[0];  // bits[1] == 0;
   temperature = bits[2];  // bits[3] == 0;

   // TEST CHECKSUM
   // bits[1] && bits[3] both 0
   uint8_t sum = bits[0] + bits[2];
   if (bits[4] != sum) return DHTLIB_ERROR_CHECKSUM;

   return DHTLIB_OK;
}
```

F) Air-quality Index(AQI):
An Air-quality Index (AQI) is used in AQMS. The AQI is an indicator of air quality, based on air pollutants that have adverse effects on human health and the environment. The pollutants are ozone, fine particulate matter, nitrogen dioxide, carbon monoxide, sulphur dioxide and total reduced sulphur compounds. figure 3 illustrate the AQI range.
The Ambient Air-Quality Standards for ANNABA reports that the safe limit for ozone is 100 micrograms per m^3 and the safe AQI value set is also 100. Therefore, the AQI itself can, indirectly, be used to measure Ozone concentration in Annaba city.

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Air Quality Index Levels of Health Concern	Numerical Value	Meaning
Good	0-50	Air quality is considered satisfactory, and air pollution poses little or no risk.
Moderate	51-100	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
Unhealthy for Sensitive Groups	101-150	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
Unhealthy	151-200	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
Very Unhealthy	201-300	Health alert: everyone may experience more serious health effects.
Hazardous	> 300	Health warnings of emergency conditions. The entire population is more likely to be affected.

Figure 3.Description of air quality index categories.

V. Results And Discussion

The proposed design were used to measure the Air-quality in several places inside the Annaba City and included different gases levels but focused mainly on measuring three main gases: Carbone Monoxide (CO) and Liquid Petroleum Gas (LPG) and NO2. A sample of obtained results from both clean environment close to Seriadi mountains, Annaba city center where there is a crowed circulation and El-Hadjar region a Metal-Steel production firm in Annaba, the results are shown in table 1, 2 and 3 respectively concerning measured area.

Table 1: Situation of air pollution in SERAIDI mountain area in Annaba city

Seraidi Co	Seraidi NO2	Seriadi LPG
0.05	1	2.05
0.8	2.5	3.5
0.75	0.8	2.7
0.48	0.8	1.9
0.87	2.4	2.9
0.79	1.7	3.04
0.61	1.5	2.9

Table 2: Situation of air pollution in Center City area in Annaba city

Center Co	Center NO2	Center LPG
20	16	75
26	13	86.9
24	17	87.4
26.78	15.68	80.6
27.58	19	76
29.15	20	79
30.15	25	78.95

Table 3: Situation of air pollution in Metal Steel factory area in Annaba city

Metal-Steel Co	Metal-Steel NO2	Metal-Steel LPG
35	56	25
34	57	24
36.7	58	38
40.58	55.8	26.25
32.78	50.15	27.8
31.99	52	30
32.58	53	30.5

Simulation results: for simulation of WSN nodes, the area is divided into parts where each part can be controlled by a node, in this case the area is divided into 9 regions, and the transmission circuit is chosen so that it can provide the adjacent nodes with the information with minimum consumption of energy.

Scenario 1: by adjusting the sliders for CO, SO2 and NO2 Gas we obtained the Red color of the region , which illustrates by node 9 the values sensed: Co=206ppm SO2=160 ppm and NO2=200 ppm

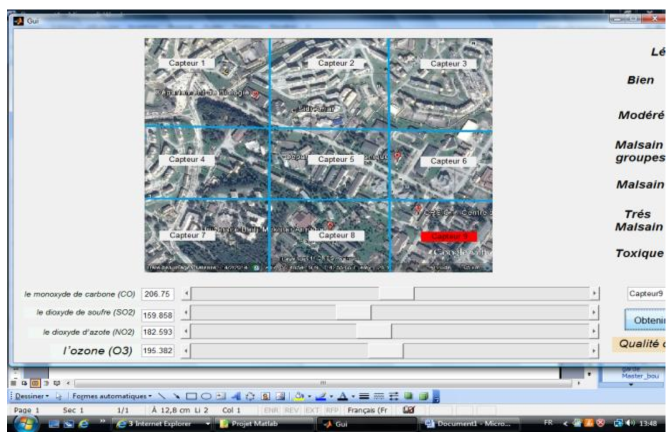

Figure 4: node 9 sensed Co=206ppm SO2=160 ppm and NO2=200 ppm levels the central control unit

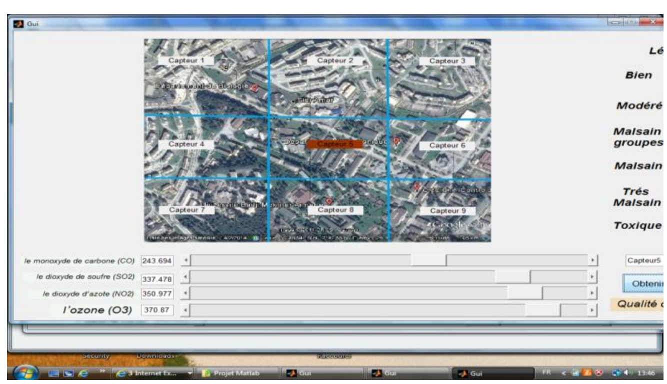

Figure 5: Node 5 sensed Co=243 ppm SO2=337 ppm and NO2=360 ppm levels the central control unit

Based on the normal gas levels of the clean air fig 3., the results indicate that there is a big difference in the gas levels of both gases (LPG and CO) which obtained from the several tests.

The results in figures 4 and 5 show respectively the quality of air in the simulated regions. In figure 4, based on gas concentrations, the AQI indicates that the air is unhealthy for both insensitive and sensitive group. In figure 5, also based on simulation results, the AQI indicates that the quality is hazardous since the quantities of gases exceed 330 ppm.

VI. Conclusions And perspectives

Air-quality monitoring System Design to assess the pollution of air in some parts of Annaba city using a micro-system, as a node in Wireless Sensor Network (WSN), is proposed in this article. WSN enhanced the process of monitoring many environmental phenomena such as the air pollution monitoring issue in proposed this paper. It provides a real-time information about the level of air pollution in different regions, as well as provides alerts in cases of drastic change in quality of air. Based on collected information, such data can then be used by the authorities to take prompt actions such as evacuating people or sending emergency response team. The proposed design is enhanced by several ways such as: selecting adequacies' sensors, calibrating these sensors for gas detection, integrating them in a WSN system controlled by an Arduino-Uno, and finally transmission to the central unit using Xbee modules. A Graphic user interface (GUI) has been presented in this work to simulate the effect of sensors on selected area . The results are interesting, improvements can be done: in providing a web service page that can provide these data to users, as well as more sophisticated sensors could be used such as MQ-135, MQ-136 and others. We think to improve this work by using mobile sensing system where public transportation infrastructure can be used[19]

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References

[1] Diego Mendez, Alfredo J. Perez, Miguel A. Labrador, Juan Jose Marron, Mar 2011, P-Sense: A Participatory Sensing Sy stem for Air Pollution Monitoring and Control, *IEEE International Conference on PERCOM Workshops, pp. 344-347.*

[2]. S. Choi, N. Kim, H. Cha, and R. Ha, 2009, Micro Sensor Node for Air Pollutant Monitoring: Hardware and Software Issues ". *Sensors 2009.*

[3] WHO Library Cataloguing in Publication Data , 1999, Monitoring ambient air quality for health impact assessment , (*WHO regional publications. European series ; No. 85), **World Health Organization 1999,** ISSN 0378-2255*

[4]. Qasem Abu Al-Haija, 2011, Toward Secure Non-Deterministic Distributed Wireless Sensor Network Using Probabilistic Key Management Approaches, *Journal of Information Assurance and Security* 6 (2011) 010-018.

[5] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, 2002, Wireless sensor networks: a survey, *Computer Networks* 38 (2002) 393–422, elsevier.

[6] http://playground.arduino.cc/Main/DHT11Lib

[7] *www.micro4you.com/files/sensor/**DHT11**.pdf*

[8] Raja Vara Prasad Y. et al, June 2011, Real Time Wireless Air Pollution Monitoring System, *ICTACT Journal on Communication Technology*,June 2011.

[9]. M. Riley, 2012, Programming Your Home: Automate with Arduino, Android, and Your Computer, *The Pragmatic Programmers, 2012.*

[10] R.A.Roseline, Dr.P.Sumathi, 2012, Local Clustering and Threshold Sensitive routing algorithm for Wireless Sensor Networks, in *the IEEE sponsored International Conference on Devices Circuits and Systems(ICDCS'12*),March 2012.(Available online at ieeexplore.com).

[11] Honicky, R.; Brewer, E.A.; Paulos, E.; White, R., 2008, N-smarts: networked suite of mobile atmospheric real-time sensors . In *Proceedings of the 2nd ACM SIGCOMM Workshop on Networked Systems for Developing Regions*, Seattle, WA, USA; ACM: Seattle, WA, USA, 2008.

[12] Volgyesi, P.; Nadas, A.; Koutsoukos, X.; Ledeczi, A. , 2008, Air Quality Monitoring with SensorMap . In *Proceedings of the 7th International Conference on Information Processing in Sensor Networks*, St. Louis, MO, USA; IEEE Computer Society: St. Louis, MO, USA, 2008.

[13] Wenhu Wang, Yifeng Yuan, Zhihao Ling, 2011, The Research and Implement of Air Quality Monitoring System Based on ZigBee , 2011 *7th International Conference on Wireless Communications, Networking and Mobile Computing*, pp. 1-4, Sept. 2011.

[14] Sharma, A.; Golubchik, L.; Govindan, R., 2007, On the Prevalence of Sensor Faults in Real-World Deployments. In *4th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks*, San Diego, CA, USA; IEEE Computer Society: San Diego, CA, USA, 2007.

[15] Saitas, Jeff;1997, *Ground-Level Ozone*; [Online] Available http://www.tnrcc.state.tx.us/air/monops/ozoneinfo.html; February 20, 1997.

[16] Xintaras, Charlie and Perry, Mike;1997, *Agency for Toxic Substances and Disease Registry*; [Online] Available http://atsdrl.atsdr.cdc.gov:8080/toxfaq.html; February 20, 1997.

[17] Technical Data For MQ-2 Gas Sensor, Website http://www.seeedstudio.com/depot/datasheet/MQ-2.pdf

[18]http://cs.smith.edu/dftwiki/index.php/Tutorial:_Arduino_and_XBee_Communication

[19] Aruljothi.R , "Air Pollution Measuring System with Mobile Sensor Arrays" International Journal of Scientific & Engineering Research, Volume 4, Issue 5, May-2013 ISSN 2229-5518

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