Design of a WSN to determine the levels of CO and noise emitted in the parking of the CORPORACIÓN UNIVERSITARIA ANTONIO JOSÉ DE SUCRE of the city of Sincelejo-Sucre

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Abstract. Wireless sensor networks (WSN) have gained great importance in recent years in different investigations and different fields, due to its wide deployment, cost and utility advantages. The constant exposure to different gases produced by combustion engines and excessive levels of noise can cause alterations in human health, especially in medium and large cities in which the vehicle fleet increases year by year. In this project a real-time contamination monitoring system is developed using wireless sensor networks for the monitoring of carbon monoxide (CO) and noise pollution in the parking of the headquarters of the Corporación Universitaria Antonio José de Sucre (CORPOSUCRE) in Sincelejo, Sucre. The data collected by the sensor nodes are sent to a computer where they can be viewed on the Serial Plotter platform. The design of the system was carried out through a site study in order to obtain the data of the variables used to get the results of the present study. The monitoring system is based on the Arduinos and XBee modules, which results in a simple design and low cost due to the characteristics of the elements used. The data obtained will allow to determine if the CO emissions and the noise levels in the parking of CORPOSUCRE exceed or not the maximum limits allowed.

1. Introduction.

In Colombia, air pollution has become one of the main environmental problems, and the degradation of air quality has caused an increase in negative effects on human health and in the same environment [1]. According to the analysis carried out in 2005 and presented in the CONPES document 3344, fossil fuels mainly used by mobile sources (cars, airplanes, trains and others) and fixed sources (mainly industrial and thermoelectric) are the largest contributors to air pollution [2]. With respect to auditory noise, the Ministry of Health of Colombia has also launched alerts with the purpose of reducing the number of cases of hearing loss that occur by the involuntary exposure to high levels of noise generated in the environment. By March of the year 2015 it is estimated that about 11% of the total of Colombian population suffered from hearing problems and among the active working population from 25 to 50 years, the prevalence of hearing loss due to noise exposure was 14% [3].

In recent years wireless sensor networks (WSN) and data acquisition systems have evolved rapidly, allowing in the new circuits greater computational power, longer transmission distances, and more accurate measurements with lower power consumption [4]. In general, the constant advances of the
WSN allowed to solve problems in various fields and today is applied to a large extent in everything that refers to intelligent environments such as smart cities, smart homes and others.

Wireless sensor networks can also be used for the monitoring of environmental variables that in values beyond permits, can cause harm to the health of human beings. In addition, these systems allow the compilation of data that later can be used to establish policies or actions that help to preserve human health. This paper presents the development and implementation of a prototype of a wireless sensor network for the monitoring of carbon monoxide (CO) and noise in the parking of the headquarters of the Corporación Universitaria Antonio José de Sucre (CORPOSUCRE) located in the La María neighborhood in Sincelejo, Sucre, Colombia; in which there is a high vehicular occupation especially in the night shift, due to the large number of students attending in motorcycles. Figure 1 shows the high congestion in the parking of headquarters A of CORPOSUCRE.

Figure 1. Top view of the parking of the main headquarters of CORPOSUCRE. Source: Authors

This work proposed the design and implementation of a prototype of measuring system that allows to determine the levels of CO and auditory noise that occur in the parking of the main headquarters of CORPOSUCRE, because these exceed the maximum levels recommended by the World Health Organization (WHO) and adopted by Colombian laws. For the development it has been decided to use the Arduino Uno modules that allow an implementation in a low cost, and the XBee S2B modules that use the IEEE 802.15.4 protocol and provide good coverage, energy efficiency and the possibility of deploying different topologies. The data will be sent to a computer to be stored and later analyzed.

The rest of the article is structured as follows: Unit 2 presents a theoretical framework with the definitions of the concepts used in the research and a description of the elements used in the implementation of the prototype. Unit 3 shows the research background and related works that served as a guide for structuring the proposal. Unit 4 presents the technological resources and the methodology used for the development of the measurement system and the communication of the data. In units 5 and 6 the results and conclusions are presented respectively; and finally the conclusions and recommendations are presented.

2. Theoretical framework.
By resolution 2254 of the year 2017, the Ministry of the Environment of Colombia established six criteria of pollution: particulate material less than 10 micrometers (PM10) and less than 2.5 micrometers
(PM2.5), sulfur dioxide (SO2), dioxide nitrogen (NO2), ozone (O3) and carbon monoxide (CO) [5]; these are the ones that cause greater risks in the population, and therefore, must have control of maximum permissible levels. For this project measurements of the concentration of CO will be made, this can be produced by the combustion of natural gas, gasoline, kerosene and other substances; and for which the Ministry of Environment establishes maximum values of 5000 μg / m3 for an exposure time of eight hours and 35000 μg / m3 for a one-hour exposure. In the same resolution, the Air Quality Index (AQI) was adopted for the implementation of a system to report the state of air quality based on a colour code, which must be taken into account to reduce the exposure to high concentrations of air polluted into the population. Table 1 shows the general description of the AQI index.

**Table 1.** General description of the Air Quality index. Source: [5].

| Range  | Colour | State of the air quality                  | Effects                                                                 |
|--------|--------|------------------------------------------|------------------------------------------------------------------------|
| 0 - 50 | Green  | Good                                     | Air pollution supposes a low risk to health.                           |
| 51 - 100 | Yellow | Acceptable                              | Possible respiratory symptoms in sensitive population groups.          |
| 101 - 150 | Orange | Harm to the health of sensitive groups   | Sensitive groups may have effects on their health.                     |
| 151 - 200 | Red    | Harmful to health                        | All individuals can experience effects on their health. Sensitive groups may experience more serious health effects. |
| 201 - 300 | Purple | Very harmful to health                   | Alertness means that everyone can experience more serious effects on their health. |
| 301 - 500 | Brown  | Dangerous                                | Health warning. The entire population can have serious adverse effects on their health and they are prone to be affected by serious health effects. |

The same resolution also presents the cuts of the air quality index with respect to the pollutants criteria, which can be seen in table 2.

**Table 2.** AQI cut-off points for carbon monoxide. Source: [5].

| AQI   | Colour | Category                                    | CO μg/m3 8 hours |
|-------|--------|---------------------------------------------|-----------------|
| 0 - 50| Green  | Good                                        | 0 - 5094        |
| 51 - 100 | Yellow | Acceptable                                  | 5095 - 10819    |
| 101 - 150 | Orange | Harm to the health of sensitive groups     | 10820 - 14254   |
| 151 - 200 | Red    | Harmful to health                           | 14255 - 17688   |
| 201 - 300 | Purple | Very harmful to health                     | 17689 - 34862   |
| 301 - 500 | Brown  | Dangerous                                   | 34863 - 57703   |

For the calculation of the AQI, equation 1 is used:
\[ AQIP = \frac{I_{High} - I_{Low}}{PC_{High} - PC_{Low}} \times (C_p - PC_{Low}) + I_{Low} \]  

(1)

Where:

AQIP = Air quality index for the pollutant P.

CP = Measured concentration for the pollutant P.

PCHigh = cut point greater than or equal to CP.

PCLow = Cut point less than or equal to CP.

IHigh = Value of the AQI corresponding to the PC High.

ILow = Value of the AQI corresponding to the PC Low.

With regard to noise levels, the exposure of humans to very high levels of sound pressure can lead to loss of health and other problems such as sleep disorders, anxiety, depression and changes in behavior [3]. Resolution 0627 of April 2006 of the Ministry of Environment defined the maximum allowable levels of noise emission expressed in dBA, and it categorizes the universities as sector B for tranquility and moderate noise, for which the maximum permissible emission standards of noise are 65 dBA in the daytime (7:01 to 21:00 hours) and 50 dBA in the night time (21:01 to 7:00 hours) [6].

3. Related works.

Air pollution and excess of noise levels are problematic that occur in different parts of the world and for this several measurement and monitoring systems have been implemented. To continuation are some publications and reports that are related to the development of the measurement system proposed to CORPOSUCRE's parking and where are shown the different tools used - in Colombia and abroad - to address the problem of measuring air pollution and of noise levels.

3.1. Prototype system for the wireless monitoring of air pollutant gases developed under free hardware and software platforms.

Students of the Electronic Engineering and Telecommunications program of the Escuela Politécnica Nacional de Ecuador designed and implemented a prototype system for the wireless monitoring of carbon monoxide (CO), Ozone (O3) and nitrogen dioxide gases in order to monitor the quality of the air in some sectors of the city of Quito. The prototype has a global positioning system (GPS) that allows georeferencing with latitude, longitude, time and date every measurement made. The information of the variables measured at each monitoring point are received through an Arduino UNO module, which performs functions of acquisition and processing of the data; which are subsequently consolidated into a set of data, for which a Single Board Microcomputer Raspberry Pi is used. Finally, the information is sent through a cellular network to a reception system for processing and storage. Among the main conclusions, the authors indicate that the system allows the wireless monitoring of gases following the pre-established requirements in the project [7].

3.2. Design and implementation of a basic gas analyzer for vehicle emissions (HC, CO and CO2), developed under the Android platform.

Researchers from the Universidad Surcolombiana de Neiva, Colombia; developed and implemented a vehicle gas analyzer (CO, CO2 and HC) with wireless communication through a Wifi Wasp Mote Pro 1.2 module that operates under the Arduino platform. For real-time monitoring via a smartphone, the Android operating system was adapted to the embedded Libelium system board. Among the positives
results of this project, the main was that the values obtained by the basic gas analyzer are stable, reliable
and reproducible. However, the authors indicate that it was not possible to make comparisons between
the data obtained and those thrown by the measurement system such as those used in revisions on
automotive diagnostic centers. [8].

3.3. **Design of a wireless sensor network for the monitoring of the vehicular traffic and CO2 pollution
in an urban sector.**

Students of the electronic engineering program of the Universidad Politécnica Salesiana de Cuenca of
Ecuador developed a vehicular behavior monitor system to measure concentrations of carbon dioxide
(CO2). The developed prototype consists of a wireless network based on the Zigbee standard with XBee
modules with four sensor nodes and a coordinator. The sensors are responsible for sending the data via
wireless to the coordinator, who through a graphical interface developed in JAVA, presents the behavior
described by the measurement curves. The information is stored in a web server linked to MySQL. In
conclusion, the authors affirm that the implemented wireless sensor network is reliable, since there was
no interference or loss of information taking into account the maximum link distance and line of sight
conditions; this made the network register efficiently the concentrations of CO2 [9].

3.4. **Implementation of the API mode in a WSN sensor network for the measurement of auditory
contamination**

The student Milton Vinicio Cacuango of the Universidad de las Américas, designed and implemented a
system for measuring the levels of auditory contamination in some of the most affected areas of the city
of Quito, Ecuador, for which he used the API mode in a WSN network. The system is composed of a
sonometer that is responsible for measuring the noise level at a specific point, a GPS to determine the
position of the node and an XBee wireless device for transmit the data at an approximate distance of 1.2
km from the Gateway to the node and the API frame, for the transmission of data from the node to the
coordinator and vice versa. The results presented show that the developed system was able to measure
noise levels in intervals of 48 dB to 80 dB [10].

3.5. **Design of a noise measurement tool based on Arduino-Raspberry PI technologies.**

This system is one of the phases of a macro project, of the Universidad de la Corporación Universitaria
Americana, called "Study on the Use of Free Software in the MSMEs of the Colombian Caribbean
Region" in which a technological tool was designed to measure the levels of auditory contamination in
closed spaces. For the development of this system was worked with free hardware technologies such as
Arduino and Raspberry, and for the sound measurement we used a DfRobot sensor 0034. Finally, the
administration of the information was done with the MySQL database. Although the article doesn't show
definitive results, the authors indicate that the tool will allow the community to control, monitor and
analyze auditory contamination in enclosed spaces. So in a future will allow to design strategies to
minimize the impact on human health caused by exceed the maximum values marked by the law [11].

3.6. **Evaluación de la calidad del aire en la ciudad de Sincelejo, departamento de Sucre, Colombia.**

In the case of the city of Sincelejo, Sucre; only the results presented by the Corporación Autonoma
Regional de Sucre (CARSUCRE) about measurements made in August 2014 from four stations of
measure of air quality, specifically particulate material, located in four points on the capital of the
department. The measurement of auditory noise is not included. The results indicate that PM
measurements weren't obtained above the maximum allowable. For the study PM10 equipment was
used, located in two branches of the University of Sucre, another in the CARSUCRE headquarters and
another one in a high vehicular traffic lane. [12].
4. Devices and tools used in the measurement system.
This project is framed in Colombian legislation. For the measurement of CO the resolution 2254 of the year 2017 of the Ministry of Environment and Sustainable Development was taken into account, and for the measurement of noise, Resolution 0627 of 2006 of the Ministry of Environment [5]; Housing and Territorial Development was considered. In the design of this system free hardware technologies were used due to the facilities offered by these tools in terms of costs and use. Below the different devices used in the carbon monoxide and noise level measurement system installed and tested in the parking of the main headquarters CORPOSUCRE are presented.

4.1. Arduino Card
Arduino is an open source platform that was designed to facilitate electronic projects. It can be used to develop interactive objects that work without being connected to a computer, in addition to taking information from the environment through sensors connected to its analog and digital inputs, controlling lights, motors and others solenoids in a direct way or from controlling signals generated by their outputs. It has a graphical development environment that uses a processing/wiring programming language and a boot manager. Another features of Arduino are: low cost, multi-platform, open source and extensible hardware [13]. In terms of hardware, it consists of a microcontroller and input and output ports. In the design of the system for this project, an Arduino One board was used as shown in figure 2, which has the following characteristics: ATmega328 microcontroller, input voltage 7-12V, 14 digital I/O pins (6 outputs) PWM), 6 analog inputs, 32k of Flash memory and 16MHz speed clock.

![Arduino One programmable card](image)

Figure 2. Arduino One programmable card. Source: [13]

4.2. MODULE MQ-9
It is a carbon monoxide (CO) and fuel gas detector sensor. Among its main features are its adjustable sensitivity, digital and analog output and voltage of 5V. The conductivity of the sensor is higher along with the increasing gas concentration. It has a high sensitivity to carbon monoxide, methane and liquefied petroleum gas (LPG). The sensor could be used to detect different gases that contain CO and combustible gases, and its sensitivity can be adjusted through a potentiometer [14]. In figure 3 can be seen the MQ-9 sensor and its sensitivity curve.
4.3. MAX9814 MODULE.
The MAX9814 microphone, like the one presented in figure 4, is a microphone amplifier with automatic gain control. It also has a low noise preamplifier, variable gain amplifier, output amplifier and a bias voltage generator. Automatic gain control reduces "loud" sounds that are close to the microphone in order to avoid saturation in the audio, and amplifies sounds that are generated at a greater distance [15].

4.4. XBEE PRO S2B
Xbee chips are wireless communication modules that work under the IEEE 802.15.4 standard and are manufactured by Digi International. This type of devices allows the creation of point-to-point and point-to-multipoint networks for applications where high data traffic and low latency are required. In addition, XBee modules offer the possibility to configure saving modes to reduce energy consumption [16]. For this investigation, modules of the series 2 were used, such as those shown in figure 5, and among its main characteristics are the maximum transmission rate of 250 Kbps, a coverage range of 1.6 km, output of 63mW, 8 digital I/O pins and local or wireless configuration.
4.5. **SHIELD XBEE - ARDUINO**

To use an XBee module with Arduino is needed a Shield or an adapter to connect the serial port of the XBee chip with the one of the Arduino module. To use or configure an XBee module with a computer you need an adapter that usually has an FTDI chip that acts as a gateway between the serial port and the USB [17]. Figure 6 shows the image of an adapter similar to the one used in the project.

![Figure 6. Adapter from XBee to Arduino. Source: [17].](image)

5. **Methodological framework**

The development of this project falls into the category of "technological development project" according to the typology established by Colciencias, because the result is a prototype for his first validation of a process in which is looking to reduce the initial uncertainty raised with respect to carbon monoxide and auditory noise concentration levels in the parking of the headquarters A of the Corporación Universitaria Antonio José de Sucre of Sincelejo, Sucre. The research is an experimental type, since different tests and trials were carried out in order to optimize the functioning of the measurer system.

5.1. **Technological resources**

The technological resources with which it is expected to fulfil the project's objectives are:

- Laptop.
- Smartphone.
• Broadband internet connection.
• Academic and/or scientific database.
• Search engines for scientific and/or academic information.
• Ofimatic applications.
• CAD Software for electronic design.
• Programming software.

5.2. Research procedure.
Five stages were established in the methodology in order to achieve the objectives proposed in this project. Next, each of the phases is detailed:

5.2.1. Selection of design features of the tool. In the initial phase of the development of the carbon monoxide and noise monitoring system design, the following problems were considered: device selection, range and precision of the measured variables, processing and data transmission. The ease of use and acquisition of tools in the market was also considered.

5.2.2. Recognition of the performance perimeter of the wireless sensor network. The identification of the place where the measurements are carried out helps to identify the propagation characteristics of the environment and to clarify if the type of link is with line of sight (LOS) or without line of sight (NLOS). This step will support the selection of the communications standard and the components for communication. The area where the system operates is 669 square meters (m$^2$) and it turns out to be a scenario with little or almost no vegetation. The distance between the data measuring point and the receiver's location is 48.09 meters with no line of sight.

5.2.3. Identification of the electronic elements and materials for the construction of the tool. Among the general characteristics for the identification and selection of devices, low cost, low energy consumption, easy handling, easy assembly and that they were easily configurable were considered. In the case of the sensors, the accuracy of the measurements and the compatibility with the other elements were taken into account, in addition to the range. Regarding of the communication stage, the distance between transmitter and receiver and the data rate was mainly considered, but also the scalability so that in the future the number of sensor nodes could be increased. Finally, in the case of data processing, the selection features include the number of I/O ports, the ease of handling and robustness.

5.2.4. Selection of the topology. Taking into account the physical characteristics and disposition (pedestrian passages and parking spaces), of the parking of the A headquarters of Corposucrè, the installation of a single measurement point located at the entrance of the institution was determined, which also allows obtaining data of the concentration of CO and noise level of the motor vehicles that circulate in the street that gives access to the University. Although a point-to-point topology is sufficient for the proposed system, a star configuration was decided in order to allow more measurement points to be added in the future and thereby ensure the scalability of the network.

5.2.5. Assembly and testing of the system. The elements mentioned in the third stage are connected with the arrangement shown in figure 7. The operation of the prototype is as follows: the MQ-9 sensor performs CO detection and measurement, and the Max-9814 sensor is used to detect sound changes. The first one has the adjustable sensitivity to have an adequate reading to the system. The MQ-9 has a digital output through a comparator with adjustable range and an analog output that can be measured with any microcontroller or development card with ADC. The second one includes an electret microphone from 20 to 20KHz, the center of this sensor is the MAX9814 amplifier which has a series of configurable options. By default, the maximum
gain level is 60dB but it can be varied to 40 and 50 dB bypassing the Gain, VCC and GND pins. The output from the amplifier is around 2Vpp max on a base of 1.25V DC.

The signals obtained by the sensors are transmitted wirelessly to a PC through the XBee modules. The acquired signal enters into the Arduino card and is amplified so that it reaches the final user's visualization for its respective interpretation of the data and decision making.

To perform tests, the carbon monoxide measurement system was installed 48 hours in advance because the MQ-9 sensor must be subjected to a preheating process for its calibration. The tests were always carried out from 6:00 p.m. to 9:15 p.m. because it is the time zone with the highest occupation on the parking, more vehicular traffic and also increases the student population and the teaching staff. In this stage, the results obtained allow to determine in an initial form the utility of the system.

![Diagram of the final prototype](image_url)

**Figure 7.** Diagram of the final prototype.

### 6. Results.

The calibration method for each of the sensors was by trial-error. For the case of the gas sensor, the characteristic curve delivered by the manufacturer was used as reference, that curve can be seen in figure #3. For the measurement of dB, a recommended ratio was used for this device. This relationship is determined by the manufacturer.

The prototype was configured with a star topology with simplex communication in coordinator-slave mode and is capable of recording information of carbon monoxide concentration (in ppm) and sound power (in dBA). In addition, each measure made by the node is recorded with the time it was made, in order to identify the times in which there is a considerable increase or when the maximum permissible values are exceeded.

Tests were performed with the X-CTU software to measure the signal strength indicator received by RSSI (for its acronym in English of Received Signal Strength Indicator) in the scenario considered. The results indicated that for a line of sight link, the RSSI value didn't decrease below -66 dBm. However, when placing the receiver in its final location, the link turns out to be NLOS and the obstacles (walls, furniture and others) cause a reduction of the RSSI to -79 dBm. In the different tests, no packet losses were registered.

### 6.1. Discussion.

In this section highlights the main limitations of the prototype that affect the accuracy of the results:

- The calibration of the MQ-9 sensor requires a 48-hour preheat by technical specifications of the manufacturer for optimal operation of the device. In the event of a disconnection in the power system, the preheating must be re-started.
• The system at been a prototype requires more evidence to help to determine the validity of the results. No comparisons have been made with certified equipment or certified reference points.

• For measuring ambient noise, the system must be adapted to the standardized measurement conditions in the resolution 0627 of 2006 in order to validate the data thrown by the measurement.

• The levels of RSSI obtained, and the number of packages sent and received indicate that the coverage level of XBee equipment is optimal for the characteristics of the scenario and propagation object of study. However, it is necessary to study another location for the receiving system to determine if the received signal strength level can be improved.

Conclusions and recommendations
At the end of this prototype, a low cost noise and CO monitoring system was achieved, with wireless communication to obtain contamination levels of the variables mentioned above through a network of wireless sensors working with the ZigBee standard.

Considering the data delivered by the manufacturers of the sensors in the data sheets. The prototype provides favorable results, so that the measurement and monitoring of CO and noise levels have been successful. In order to improve the accuracy levels of the measurement system, in the future comparison tests will be carried out with certified polluting gas measurement equipment such as those found in automotive diagnostic centers. During the measurement intervals no CO and noise levels above the maximum values allowed by Colombian regulations were detected. However, it is recommended to conduct a more extensive measurement campaign, including all the hours of the academic day. So that more concrete results can be obtained.

It can be evidenced that the communication by Xbee is stable and reliable according to the distance to which the coordinator and the slave are connected. It can also be noted that it is an accessible device compared to others devices on the market and also allows working in real time with very low delays. Although RSSI levels are satisfactory and no packet loss was registered, it is recommended to consider other location points for receivers as well as a range test for the purpose of increasing system performance and signal strength in order to provide greater stability to data transmission.

As future work, it is recommended to increase the number of measurement points that include not only the CORPOSUCRE facilities, but also the access roads to the institution which present a vehicular flow at different times of the day. It is also recommended to measure other pollutants including in the law and that may affect the health of people and the environment.

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