Environmental parameters monitoring system with an application interface for smartphone

Jorge Ramos[1], André Teixeira[2], Carlos Arantes[3], Sérgio Lopes[4] and João Sena Esteves[4]

[1] Smart Grid Division, Efacec, Porto, Portugal
[2] Engineering School, University of Minho, 4800-058 Guimarães, Portugal
[3]Protection, Automation and Control Division, Efacec, Porto
[4]Centro Algoritmi, Engineering School, University of Minho, 4800-058 Guimarães, Portugal
jorge.silva.ramos@efacec.com, a71913@alunos.uminho.pt, carlos.arantes@efacec.com, sergio.lopes@dei.uminho.pt, sena@dei.uminho.pt

Abstract. Air pollution has become a major cause of health problems and mortality. Monitoring systems based on fixed stations are not able to adequately characterize air pollution on a large area such as city. This paper describes the study, development, implementation and validation of a mobile system for monitoring environ-mental parameters. The system consists of a sensor network, a communications system, a web application and a smartphone application. The sensor network is scalable as it has a bus topology and can collect data about nitrogen dioxide and particulate matter. The communications system aggregates the collected data and sends it to a remote web server using the HTTP protocol and a 3G mobile network. The web and the smartphone applications provide ways for viewing the data stored on the remote web server. The Google Maps API was used to represent the obtained records on a map. All system components were tested individually and, at a later stage, in an integrated manner. The results obtained in tests with the developed system were compared with the results from fixed stations. The measurement errors were less than 10%.

Keywords: Environmental monitoring, mobile monitoring system, HTTP protocol, smartphone application.

1 Introduction

The daily life of society has been affected by the increase in environmental pollution, either at atmospheric level or at sound level. According to a report by the European Environment Agency in 2016, air pollution was responsible for 467 000 premature deaths in Europe [1]. In order to reduce these numbers, systems have been implemented to monitor ambient air. These systems allow the creation of air quality indicators and, consequently, the determination of critical points and the implementation of air pollution prevention and reduction measures. Monitoring consists of a "series of observations and measurements of some physical, chemical or biological variables, which

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make it possible to understand and predict some environmental changes" [2]. The main polluting substances monitored are carbon monoxide, nitrogen dioxide, sulfur dioxide, ozone and particulate material [1][3]. This last substance consists of solid or liquid material that is suspended on the air in the form of particles [4].

Traditionally, air monitoring is done from networks of stationary stations. These networks (still used today) are made up of stations with air quality sensors, installed in strategic areas of the cities. From the data fusion from each station, it is possible to measure air pollution in respective city spots. To characterize the air pollution in the city, the number of stations that make up the network should be proportional to the area to be monitored. For example, in 2017 a monitoring system of this type was introduced in the Philippines. This system consists of 4 new large fixed stations, which allow the monitoring of particulate material, sulfur dioxide, ozone and nitrogen dioxide in real time. This system constantly measures the levels of concentrations of pol-luting substances and generates, on an hourly basis, the average for each one [3].

Despite their high dissemination, these networks of fixed stations require high installation and maintenance costs. Thus, most cities contain a reduced number of stations for the area to be covered, making the data collected inefficient and the characterization of the environment incomplete [5]. For example, the city of Beijing, with about 16.800 $km2$, is covered by only 35 monitoring stations [6]. In this way, areas outside the reach of stations are estimated using mathematical methods, making it impossible to detect local changes in air quality, such as sporadic emissions and heavy traffic [8] – [10].

The main objectives of the work described in this paper were the study, development, implementation and validation of a mobile system for monitoring environmental parameters. The goals of the project were:

a) flexibility to install a variable number of sensors to measure different environmental parameters;

b) georeferentiation of every sensor reading, enabling to provide detailed maps of air quality on given areas;

c) to provide the data through multiples platforms, web and mobile, in real-time.

2 Related Work

This chapter presents two examples of existing air quality monitoring stations, one fixed and one mobile, with the latter being implemented in vehicles. The main characteristics, advantages and drawbacks of these two types of stations are summarized.

2.1 Fixed Monitoring Station

The CitySense project, implemented in Cambridge, is an example of the implementation of fixed stations [11]. Each station is made up of a set of sensors capable of measuring temperature, relative humidity, wind speed and atmospheric pressure. In addition, it also consists of a box of reduced dimensions (about 8x8 cm), containing carbon dioxide sensors and all the necessary hardware for data communication via GSM (Global System for Mobile Communications). The carbon dioxide sensors used are Vaisala GMP343. These sensors are characterized by having low energy consumption, good accuracy and a total cost of around 2500 € [11][12].

From this example, it may be concluded that the use of small stations scattered around cities is a possibility for air quality monitoring systems. Since the cost and size of these stations is significantly less than that of conventional stations, it is possible to introduce a larger number across cities. In this way, more values are obtained for the area to be covered, improving the characterization of air quality [6]. Although this is just one example, it has the characteristics common to other fixed systems described in [6]. In Table 1, the advantages and disadvantages related to monitoring from fixed stations are pointed out [6][7].

Table 1. Main advantages and disadvantages of a fixed monitoring station

Advantages	Disadvantages
Use of high-quality hardware, allowing the acquisition of accurate and reliable data	Careful placement of monitoring stations due to the lack of air pollution standard
Lack of localization systems	Placement of a number of stations proportional to the area to be covered
Use of several sensors without constraints regarding the physical dimensions and total weight of the system	Use of mathematical methods in order to predict air quality in unmonitored areas (extrapolation)
Easy system maintenance	Limited measurement area
	High cost of implementation

2.2 Mobile Monitoring Stations

Google, in partnership with Aclima, a company in the field of air quality, has implemented three street view cars systems that collect data about air quality. The main polluting substances monitored were nitrogen monoxide, nitrogen dioxide and black carbon particles. Data collection was done for one year across all streets within the residential, industrial and commercial areas of Oakland, California. After that year, all the data obtained were analyzed, concluding that this type of monitoring reveals a “remarkable and stable heterogeneity in the daily concentrations of some pollutants” [13]. In addition, it was found that some areas within the city have a greater air pollution, for example, in the vicinity of a metal scrap the levels of nitrogen monoxide and dioxide were higher than the levels of the rest of the street. The same happened near highways, that is, as the collection was carried out farther from the highways, the concentrations of the parameters decreased [13].

This monitoring system consists of an air collection system on the top of the car and a measurement system implemented in the trunk of the car. The collection system enables the ambient air to be sent to the measurement system, ensuring that it is constantly changed. Regarding the measurement system, it consists of high cost laboratory analyzers, which allows to acquire precision and accuracy in the measurements made. Whenever new measurements are collected, they are sent to the Aclima cloud where they will be further processed [13]. Table 2 shows the advantages and disadvantages related to monitoring from mobile stations [14].

Table 2. Main advantages and disadvantages of a mobile monitoring station.

Advantages	Disadvantages
Data acquisition in different locations	Data redundancy directly related to the number of vehicles traveling in an area
Visualization of the values collected in different locations in real time	Introduction of a localization module to geo-reference the values obtained
Lower cost in the implementation and acquisition of the system	Introduction of a communication module for sending data from the respective collection site. Thus, it will be necessary to use mobile data, leading to an increase in the cost of use

3 System Architecture

This section describes the components and procedures of the proposed monitoring system. The developed system architecture is represented in Fig.1.

Each Monitoring Unit is based on a microcontroller connected with sensors. These units are responsible for collecting data related to the environmental parameters and sending them to the local Central Unit through a LIN bus. The LIN bus implements a sensor network that offers: (1) scalability, to increase the number and variety of sensors, for example to monitor also cabin air parameters such as CO2; (2) easier deployment in vehicles, by minimizing the cables necessary to interconnect exterior/engine and cabin units and facilitating the installation of sensors in different vehicle locations. The sensors used consist of one MiCS-4514 to measure the Nitrogen Dioxide (NO2) and a HPMA115S0-XXX to measure the particulate material, namely PM2.5 and PM10. In addition, a DHT 11 sensor was implemented to measure temperature and relative humidity measurement. These sensors have the best cost-benefit ratio for the proposed system.

The Central Unit consists of a microcontroller, a GPS module and a 3G communications module. This unit receives the data collected from Monitoring Units through LIN BUS protocol, groups it and sends it to the Cloud Service along with geographic coordinates.

The Cloud Service saves the data received from central units and makes it available to client applications, namely a web application and an Android application that allows users to easily access real-time air quality data for the location they are at.

In the android application, the AQI (Air Quality Index) values are computed using the data read from the Cloud and represented on a map. This is explained in more detail in subsection bellow.

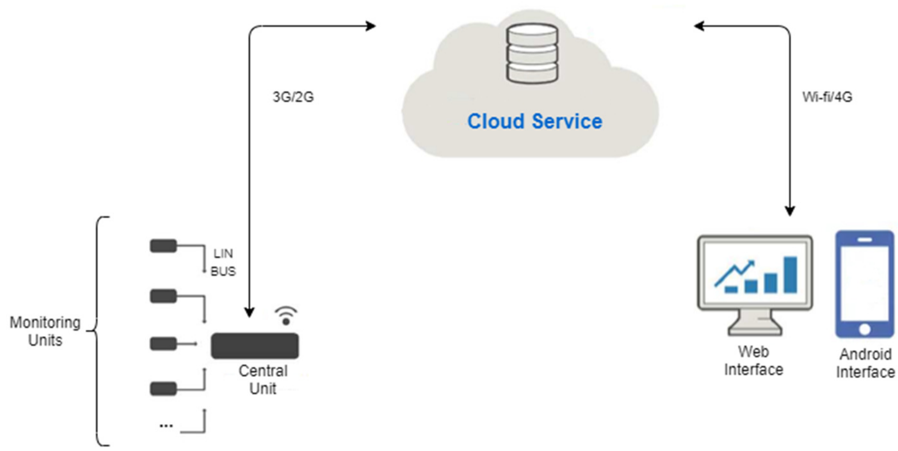

Fig. 1. Block diagram of the monitoring system, adapted from [15].

3.1 Monitoring Units and Central Unit

The Monitoring Unit architecture is presented side by side with the respective PCB in Fig.2. As shown in the figure, the monitoring units are equipped with a UART, I2C and ADC interfaces that allow the choice of parameters and sensors to be used by the end user. In addition, a connector for gas sensors of the MQ series was introduced as they fit into low-cost sensors for measuring a wide variety of gases. The unit is powered by the 12 V voltage of the Central Unit and LIN protocol is used for communication between all units.

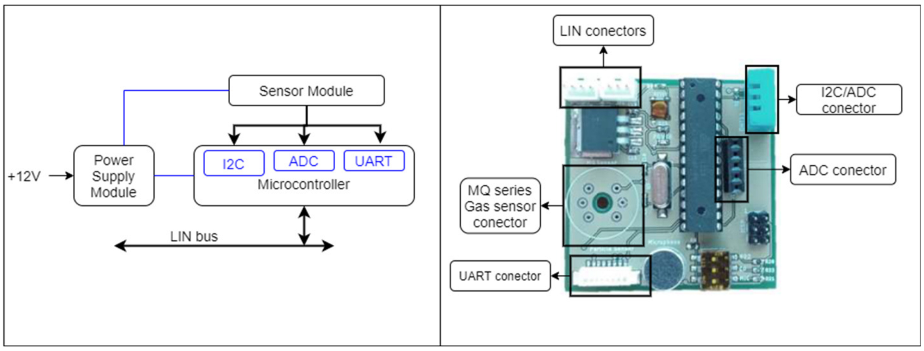

Fig. 2. Monitoring Unit architecture on the left and the respective PCB on the right.

Fig.3 presents the architecture and the PCB of the Central Unit. The board has a 3G modem, a GPS module and connectors for the LIN and CAN communication proto-col. The 3G module was chosen considering the available budget. The CAN Bus is used to enable communication with the car's CAN network. This unit is powered by a +12 V power supply, such as a car battery or cigarette lighter adapter.

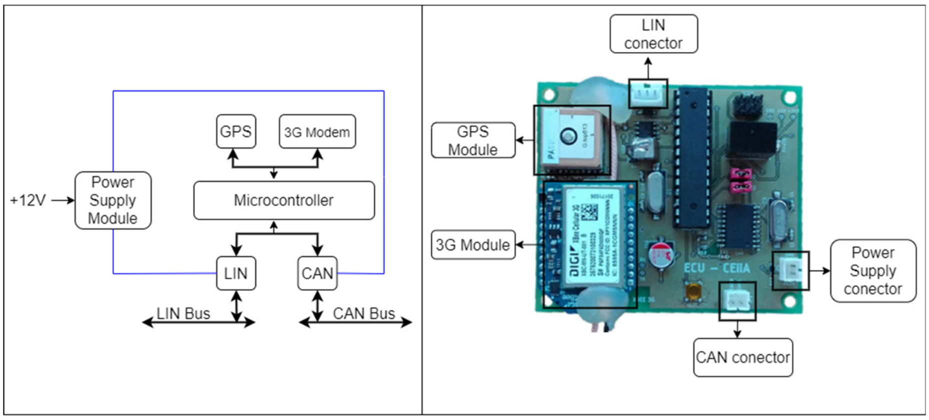

Fig. 3. Central unit architecture on the left and the respective PCB on the right.

4 Data Transmission and Storage

The Cloud Service is based on the ThingSpeak IoT platform. This platform provides storage, analysis and real time data visualization. It stores data in channels, each one with a maximum of 8 data fields. In the developed Cloud Service, each channel corresponds to a Central Unit, and each field is a measured parameter (temperature, humidity, PM2.5, PM10, NO2, latitude, longitude).

The communication with Central Units as well as client applications is implemented using HTTP protocol. For sending data, an HTTP POST method is used by Central

Units in which, the data frame sent contains the sensor measured values and the location at which they were obtained. A message is sent periodically every 10 seconds.

The HTTP POST message structure is presented in Fig.4 and displays the fields for each monitored parameter. It is important to note that field 6 is not defined since it is used for testing purposes. After receiving the message, the Cloud Services assigns this dataset an identifier (entry_ID).

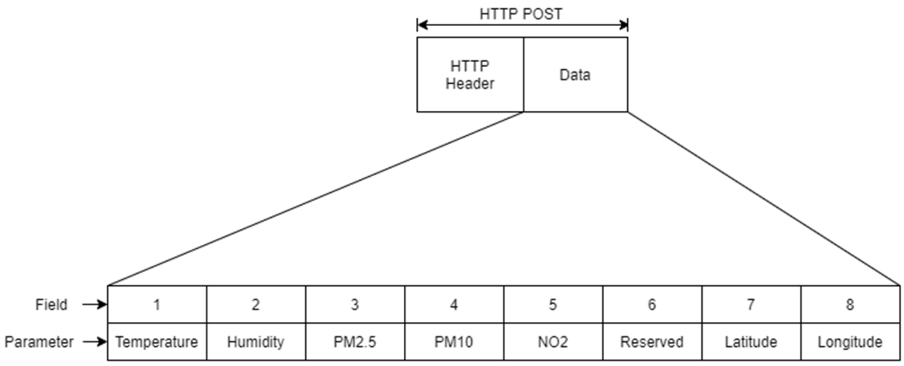

Fig. 4. HTTP Post frame structure.

Client applications request data from the Cloud Service using HTTP GET method. The desired channel is defined in the URL and the reading api key required for private channels is added as query parameters. The response contains the last saved data in a json format as shown below:

{"created_at":"2020-11-29T12:13:23Z","entry_id":142,"Temperature":"15","Hu-mid-ity":"60","PM2.5":"1.3","PM10":"6.0","NO2":"25.1","Latitude":"41.407067","Longitude":"-8.520499"}

The first key / value pair corresponds to the time the data was recorded in the Cloud. The keys field 1 to field 5 and their respective values represent the environmental parameters sent. Finally, the last two key / value pairs correspond to the location (latitude and longitude respectively).

5 Mobile Application

A mobile application was developed to present the data collected by the mobile environmental station. It is an Android app that computes the Air Quality Index (AQI) for a central unit and shows their data on a map. The AQI consists of a color classification for the different levels of the air quality. The color assignment is related to an AQI value calculated from the pollutant concentrations. The Android app was writ-ten in

Java and it uses the Google Maps service API. Its interface consists of a unique Activity with a map where colored markers are displayed according to the calculated AQI value. The markers also show the individuals sensor values obtained from the Cloud Service.

The app flowchart is represented in Fig.5. First, an HTTP GET is made to obtain the json data that contains the latest sensor readings. The entry_ID value is compared with the last entry_ID to ensure that a new marker is only drawn when a new dataset is uploaded to the Cloud. If the entry_IDs does not match, the AQI calculation for each pollutant is performed by comparing the values of concentration with a reference table values, using the following mathematical model:

$$I_p = \frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}} \left(C_p - BP_{Lo}\right) + I_{Lo} \quad (1)$$

Where:

- I_p is the index for pollutant p;
- C_p is the concentration of the pollutant p;
- BP_{Hi} is the concentration breakpoint that is greater than or equal to C_p (Table 3);
- BP_{Lo} is the concentration breakpoint that is less than or equal to C_p (Table 3);
- I_{Hi} is the AQI value for the upper limit BP_{Hi} (Table 3);
- I_{Lo} is the AQI value for the lower limit BP_{Lo} (Table 3).

Table 3. AQI table [16]

Pollutant / Classification	PM_{10} (µg/m^3)		$PM_{2.5}$ (µg/m^3)		NO_2 (µg/m^3)	
	Min	Max	Min	Max	Min	Max
Very good 0-25	0	15	0	10	0	50
Good 25-50	15	30	10	20	50	100
Fair 50-75	30	50	20	30	100	200
Bad 75-100	50	100	30	60	200	400
Very Bad >10	100	-	60	-	401	-

Then, the final AQI value is obtained by the maximum value of the AQI calculated for each pollutant. Finally, a custom marker with the corresponding AQI color is drawn on the map. When pressing the marker, pollutant information, temperature and humidity and occurrence date are shown. All previous markers remain on the map.

This algorithm is executed every 5 seconds, so that the Cloud data is periodically read.

All these procedures are executed in background to avoid freezing the map interface.

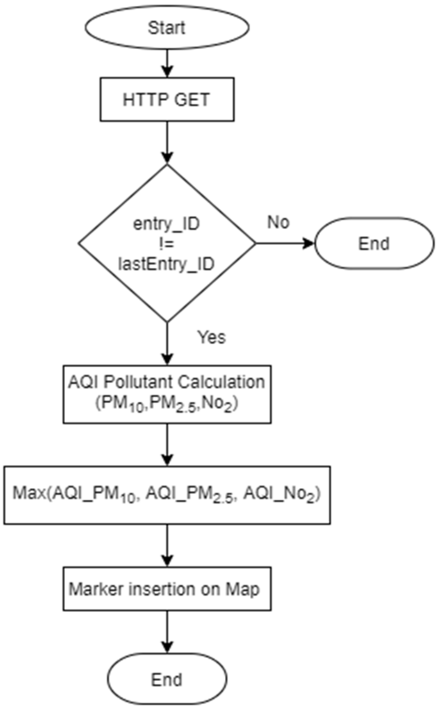

Fig. 5. Android app flowchart

6 Results

The results obtained from experimental tests carried out on the Android application, which include communication with the Cloud, are presented below in order to vali-date the system implementation.

Whenever the application starts-up, a Google map is created and the marker corresponding to the last data transmission is added. As a new marker is added the focus of the map is redirected to that point (see Fig.6). The added marker shows the color corresponding to the AQI. The marker info window was customized in order to dis-play the detailed information in a table format. To access this window, it is only necessary to click on the desired marker. On top of the info window the AQI classification obtained with the appropriate color is presented. The parameters, the measurements and the AQI value calculated for each one appear below. At the end, the time and date when the measurement took place are displayed.

The application also allows switching the map view between normal, satellite, or hybrid.

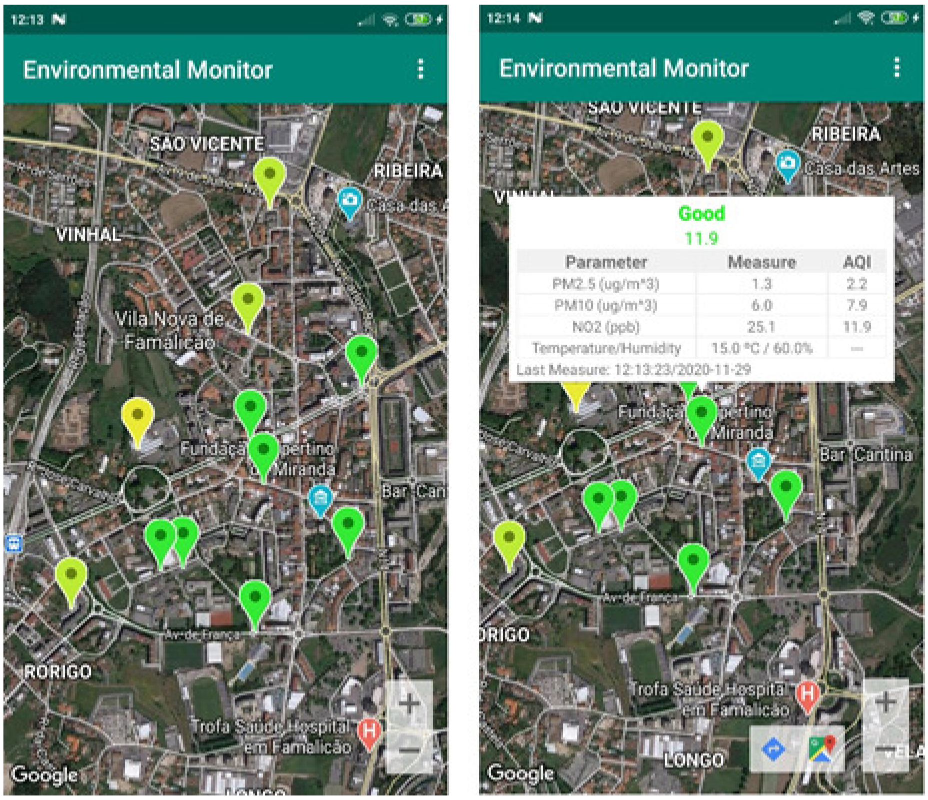

Fig. 6. Android Interface.

7 Conclusions and Future Work

The use of fixed monitoring stations has several limitations in terms of environmental monitoring. The need to estimate data for an area based on measurements made in a few places was a problem for this type of system, as it makes it impossible to create reliable air quality profiles that follow the change and the existing standards in a given area. The use of mobile monitoring stations, namely systems implemented on mobile platforms, makes it possible to take advantage of the movements of these platforms to collect data from different zones. In this way, measurements are taken in more places, achieving a better characterization of the monitored areas.

A fully functional prototype of a monitoring system was developed to be implemented in a car, which allows the monitoring of some of the main polluting substances:

particulate matter and nitrogen dioxide. This system has a sensors network that make it scalable, enabling the addition of new units for measurement both inside and out-side the vehicle. In addition, the expandability of the sensor network is also guaranteed by the modularity of the monitoring units – the existence of several interfaces facilitates the replacement of the sensors. The implemented system makes possible to send data to a remote server or to the car's CAN network. This last feature enables, for example, to generate an alert whenever the air quality of the passenger compartment is outside a defined range. The data sent to the Cloud can be available online, allowing it to be viewed by the population, as well as the definition of long-term policies to improve air quality. The smartphone application is responsible for viewing the data as it allows viewing the records on a virtual map provided by the Google Maps service and also for the treatment and processing of the data obtained. The prototype developed is a low cost system that easily provides valuable data for responsible authorities and for citizens through both web and mobile platforms.

The achieved results fulfill the proposed objectives. In the first tests, the values obtained with the new system were compared with the results from the fixed stations, obtaining measurement errors of less than 10%. In the remaining tests carried out, the system collected data in several areas, taking advantage of the car's movement. Using the system, it was found that the air quality in the city center of Vila Nova de Famalicão, Portugal, is lower than the air quality in its periphery. In order to reach this conclusion, a large number of measurements were made in each of the zones under evaluation.

Regarding future work, there are some aspects of the current system that could be improved. The following changes are suggested:

- Use of electrochemical sensors in the monitoring units to reduce the error of the measurements, obtaining more accurate values;
- Addition of an SPI interface allowing the introduction of more sensors;
- Provide wider coverage and reduce communications cost by replacing the 3G module with one that supports NB-Iot;
- Implementation of an interpolation of the obtained data to be able to provide a continuous map of air quality.

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