A Hybrid Measurement Kit for Real-time Air Quality Monitoring Across Senegal Cities

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Abstract— **Due to the huge number of ancient cars and poor quality fuels, the standard air quality limit values of particulate matter (PM) is a big concern in Senegal. PM and number of gaseous pollutants that have an adverse affect on human health increase continuously. In contrast to remaining Senegalese regions, Dakar region hosts main socio-economic and administrative activities and suffers more according to above emissions. Therefore, respiratory and cardiovascular problems are frequently diagnosed and they become a major public health problem in the country. As consequence, Senegal government has deployed six fixed stations measurement center. Nevertheless, they are not well geographically distributed, do not take account driving style, driving conditions, and consider only a few gaseous pollutants. In this paper, we present a low-cost solution based on wireless sensor networks for real-time air quality monitoring in Dakar. The system consists of carbon monoxide (CO) sensors, carbon dioxide sensors (CO_2) and particulate matter detectors ($PM10$, $PM2,5$, $PM1$). We aim to take into account more specific metrics to evaluate air quality and implement a hybrid measurement kit which can be fixed as landmarks or mobile. Indeed, the mobile kit is embedded in cars which travel across cities. The implemented kit is able to transmit collected data by $LoRa$ protocol or cellular network to a Web application for visualization.**

Index Terms— **Air quality monitoring, particulate matter, gaseous pollutants, wireless sensor network.**

I. INTRODUCTION

The number of pollution-related deaths in Africa increased to the same level as the urban population, witch was estimated at 472 million in 1990. This number is rising steadily and will reach 1 billion by 2040 World Bank forecasts [1]. This growth is a big concern since the number of deaths due to pollution-related disease increased to 36% in 20 years [2] and cost 215 billion dollar in 2013 [3]. Africa could be responsible of half of global anthropogenic emissions of gaseous and particulate pollutants by 2030 whether there is no political urban evolution change [5]. Indeed, the rapid growth according to the number of vehicles and two-wheelers, the poorly maintained motors and the use of very bad fuel quality as responsible [4]. In contrast to developing countries, transportation is the most important source of fine dust emission.

Dakar is the capital of Senegal and the most populous and urbanized region. Indeed, it hosts 0.3% of the territory and more than 80% of country's economic and industrial activities. Therefore, the estimated pollution degree is upper than the limits fixed by Senegalese national standard $NS-05-62$ [6]. The annual exposure particles rate to $PM2.5$ within the city is more than 3.4 times according to the recommended World Health Organization (WHO) threshold [5].

Few investigations have been done on the type and the source of the elements composing the aerosol were carried out in Dakar. They proved their toxicity to health [7]. To monitor the capital's pollution, Senegalese government has implemented an Air Quality Management Center (AQMC)[9]. The current measurement methodology uses expensive equipments at fixed location. The AQMC has deployed six measurement stations installed in Guédiaway, Medina, Yoff, Bel-air, HLM and Cathedral districts. Theses measurement centers are geographically distant and do not take into account several toxic pollutants. The main pollutants studied are particulate matter ($PM10$ and $PM2.5$), carbon monoxide (CO), nitrogen oxides (NOx) with nitrogen dioxide (NO_2) and nitric oxide (NO). Therefore, we aim to take into account more specific metrics to assess air quality in real time and set up a hybrid measurement kit. This kit is designed with low cost sensors and then coupled with a web platform for visualization.

An index is used to evaluate the overall air quality for a particular monitoring station. It is calculated for each pollutant measured. The maximum value is considered as the air quality index for this monitoring station. Because it represents the worst of pollutants measured. This index, called the *Air Quality Index* (AQI), is a way of calculating and responding to pollution problems. It is calculated according to the procedure described in [10]. The AQI is based on the highest standardized concentration of each pollutant.

AQI values range between 0 to 500. Air quality is satisfactory when values are below 100 and bad when its value is upper than 150. In Senegal, $AQMC$ adopts four classes of AQI. Each class corresponds to a level of health impact according to the population group. The results are posted on $AQMC$ and the Minister of the Environment website. Using the AQI, we compare the values measured by our kit with those of the $AQMC$.

Nowadays, the scarcity of information prevents the public from becoming aware of pollution related to health problems. A scalable detection platform could effectively disseminate pollution information to users who need it. We aim to take into account several metrics for a good air quality of the city. The measurement kit can be mobile and embedded in public transport for providing the city pollution map. The kit can also be fixed, in such case it is placed in the most polluted areas of the city and can provide an idea of the evolution of air pollution in Dakar city.

The paper is organized as follows. Section II describes the related work. Section III shows an overview of our proposed pollution detection kit as well describes the components that form our testbed. Section IV illustrates the performed measurements according to our real testbed. Finally, section V concludes this work.

II. RELATED WORK

Many air pollution systems in urban areas that use smart sensor network and wireless were reported in recent literature. An environmental air pollution monitoring system that measure CO, temperature and humidity reported in [11] is based on sensor node built from $OctopusII$ by the science department of $Tsing\ Hua$ National University of Taiwan. This system collects data via sensors and then the data are sent to the gateway using $CC240$ wireless transceiver adapted $IEEE$ $802.15.4$ and $ZigBee$ specification for wireless communication. According to the gateway, received data are transmitted to the database through the *Short Message Service* (SMS). During our tests, nine sensor nodes have been deployed around the busiest roads and the data from the sensors were sent every ten minutes. The results have shown a relationship between the increase in Carbone monoxide (CO) rate in different areas with road traffic.

A wearable and wireless sensor system for real-time air quality monitoring was developed in [12]. This system is subdivided into two blocks: a Mobile Data-Acquisition Unit (*Mobile-DAQ*) and a fixed Internet-Enabled Pollution monitoring Server (*Pollution-Server*). *Mobile-DAQ* uses tree air pollutions sensors including Carbon Monoxide (CO), Nitrogen Dioxide (NO_2), and Sulfur Dioxide (SO_2). The collected data are coupled with geographical position from a GPS module and all data are then automatically sent to the pollution server using a $GPRS$ module. Six monitoring stations were deployed and the results were displayed by considering a heat map on the server. The color of the positions in the map vary according to the air quality index of the pollution of the area.

Several studies proposed to measure air quality by considering a personal portable system [13], [14]. $OpenSense$ [15] set up a mobile sensor network on the roofs of buses and trams using public transport for an extensive collection data network on air quality. Devarakonda et al [16] developed a hybrid measurement kit with industrial sensor. This kit can be embedded on a car or used like a personal sensing device.

Our proposal allows us to overcome the limitation of previous monitoring systems. It is based on low cost sensors but also it allows to have real-time data on a website. Our system feature is that it can be used for fixed or mobile measurement.

III. AIR MONITORING ARCHITECTURE

The overall system architecture is shown in Fig. 1. The detection kit measures the concentration of pollutants. Collected data is transmitted to a cloud server with relevant information, such as the collection time and the GPS location of the collection point. The raw pollution data is then processed by the server and the users can visualize the illustration of pollution data in a real time map on a website. This will allow users to obtain a detailed report on street level air quality.

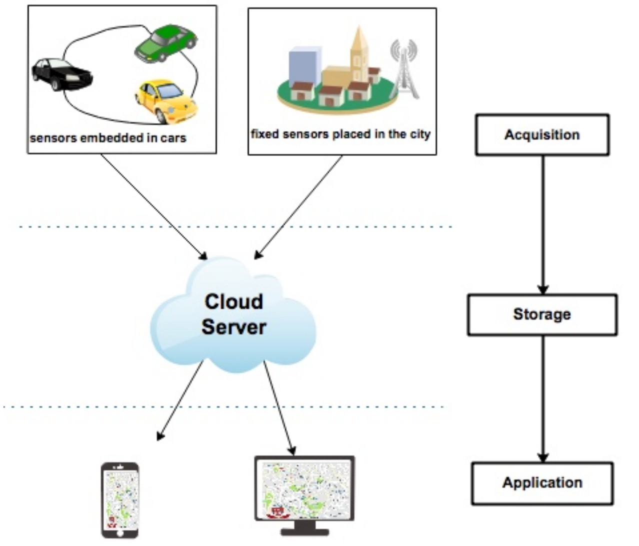

Fig. 1. Global System Architecture

As shown in Fig. 1, the detection system can be subdivided into three subsystems formed by an acquisition subsystem, a storage subsystem and an application subsystem.

A. Acquisition Subsystem

The acquisition represents the used sensors network for air quality monitoring. It can be mobile or fixed.

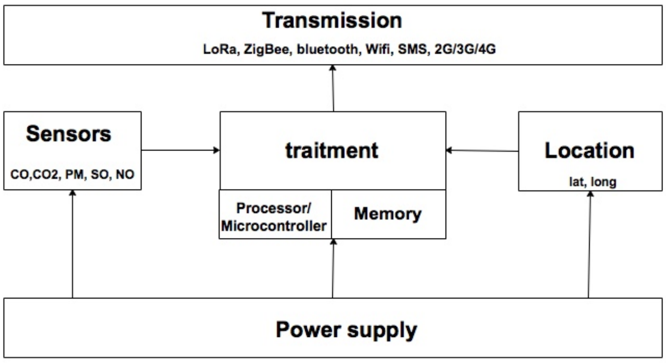

Fig. 2. Acquisition subsystem architecture

The acquisition architecture subsystem is composed by 5 units as illustrated in Fig. 2:

- **Detection unit**: it represents the sensors measurement kit. We considered several types of sensors which measure Carbon Dioxide (CO_2) [17], carbon monoxide (CO) [18] and dust particle (PM) [19].
- **Power supply unit**: it can be a solar power or battery. According to a mobile sensor, it can be connected to

the car battery as an additional source of energy.

- **Location unit**: it is composed by a GPS sensor that retrieves geographical position of the measuring areas. By using these coordinates, we provide the pollution map of a target city.
- **Processing unit**: it is formed by a processor or micro-controller for processing data from the different sensors as well as a memory for storing temporary data.
- **Transmission Unit**: with the emergence of wireless sensor networks, several works have focused on reducing energy consumption [20], [21], [22].
  Nowadays, technologies such as the Low-Power Wide Area Network ($LPWAN$) have emerged. $LPWANs$ leverage wireless links with low power consumption and enable long-distance transmission. Moreover, a study is carried out for the coverage of Dakar city by a $Lora$ network [23]. In addition to $LPWAN$, it exists other suitable transmission systems such as $Bluetooth$, $Wifi$, $ZigBee$ and cellular network ($2G$, $3G$, $4G$). Most of these transmission networks require gateways in multiple locations around the city to retrieve data collected by mobile sensors. Afterwards, with an Internet connection, the gateway sends the data to the cloud server for processing as shown in Fig. 3. If the kit owns a mobile network module, it sends directly data to the cloud without going through a gateway as depicted in Fig. 4.

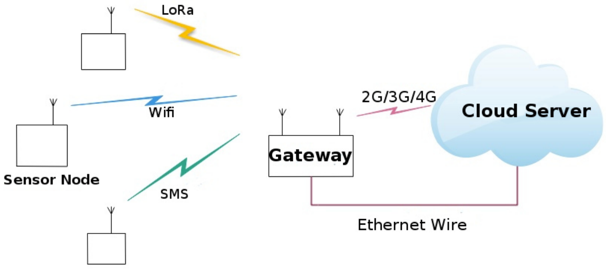

Fig. 3. Gateway-based transmission

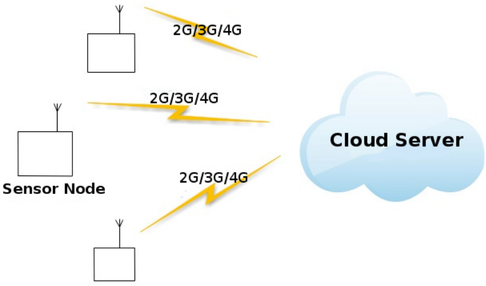

Fig. 4. Point point transmission

B. Storage subsystem

Data collected from the sensors are stored in Cloud through the storage system. This system is composed by two databases: the first one is local and the second is external and located in the Cloud. After receiving, the gateway stores the data locally. Since the Internet connection is not always stable in our countries, we write a process (daemon) to test Internet access. In case of stable connection, the data is replicated to the cloud. According to a mobile system, these data are stored directly on the cloud.

C. Application subsystem

The Application subsystem represents a web platform for data visualization. This platform presents graphs and pollution map of the city with real-time data collected. Thus, users such as the municipality, environmental protection agencies, travel agencies, insurance companies and tourist companies can connect to the platform through the Internet and check in real-time air-pollutants level using a web browser or a mobile device.

IV. ARCHITECTURE COMPONENTS

A. Brief overview on measurement kit

We consider $Arduino\ UNO$ [24] kit as a processing unit. $Arduino\ Uno$ is a micro-controller board based on the $ATmega328P$. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the micro-controller; it can be simply connect to a computer with a USB cable or power with a AC-to-DC adapter or battery for use it. The $Arduino$ board is used to connect with the detection unit which is composed by pollutant sensors. We use 3 sensors types:

- *CO_2 sensor*: it is $MQ-81$-based sensor and designed by $DFRobot$ [17]. The output voltage of the module falls down as the concentration of the CO_2 increases. The potentiometer on-board is designed to set the threshold of voltage.
- *CO sensor*: the $MQ-7$-based sensor is a simple-to-use Carbon Monoxide (CO) sensor suitable for sensing CO concentrations in the air. It can detect CO-gas concentrations anywhere from 20 to $2000ppm$. The sensitivity can be adjusted by the potentiometer.
- *Dust Sensor*: it is a $PM2.5$ *laser dust sensor* [19] designed by $DFRobot$. $PM2.5$ laser dust sensor is a digital universal particle concentration sensor. It can be used to obtain the number of suspended particulate matter in a unit volume of air within 0.3 to 10 $microns$, namely the concentration of particulate matter and output with digital interface.Finally, the $PM2.5$ *laser dust sensor* can output quality data per particle.

The geolocation unit is represented by a GPS shield [25]. This shield integrates a $LoRa$ chip. Our GPS module can calculate and predict orbits automatically using the ephemeris data (up to 3 days) stored in internal flash memory, so the shield can fix position quickly even at indoor signal levels with low power consumption. For power supply, the voltage range of the $Arduino$ board is $7-12V$. So we can use a $15V$ solar panel to power the entire device. The acquisition node is illustrated in Fig. 5.

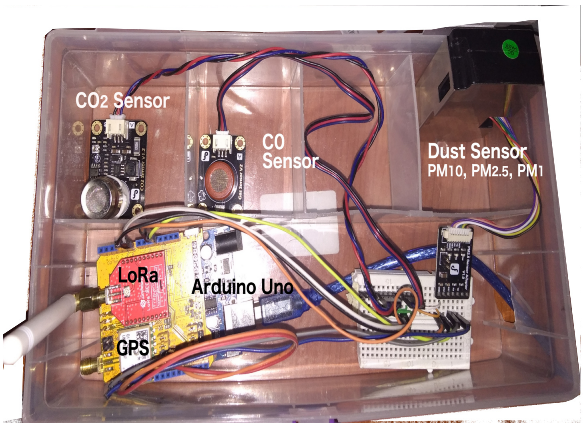

Fig. 5. Data acquisition node

B. Transmission unit

According to transmission unit we considered two options:

- *Transmission with gateway*: Here the gateway is composed of a reception module and a database for local storage. The information sent by the acquisition node by $LoRa$ is retrieved by the receiving module. This reception module is connected to a computer by a USB cable. The data is transmitted over the cable and a python program retrieves the data in a local database and is replicated to a remote database in the cloud as depicted in Fig. 6.
- *Transmission without gateway*: the acquisition system is coupled with a transmission module which enables to send data directly to the cloud without a gateway. The transmission module can be a computer cable-link to the acquisition system or mobile cellular networks shield for direct data transmission.

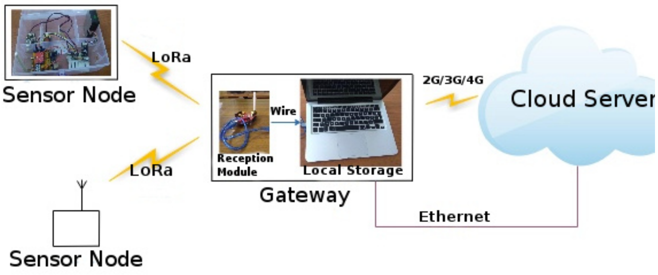

Fig. 6. Cloud-based communication architecture

It should be noted that collected data is transmitted every minute in order to obtain real time monitoring.

C. Storage and application subsystem

According to cloud infrastructure, we use $MySQL$ database for storage. The application is developed in PHP. In situation where the measurement kit is mobile, the PHP application reads pollutant data from a $MySQL$ database and plots it on a heat map using *Google Maps API*. Otherwise, if the measurement kit is fixed, we use *Highchart* which is a $JavaScript$ library for graphs visualization. Furthermore, $AJAX$ requests allow us to refresh the graphs every ten seconds in order to visualize in real time data.

D. Measurement testbed

1) Mobile kit measurement: During the first experiment, the kit measurement is embedded in the car. It is coupled with a computer for sending data with *GPS* position to the cloud. The kit is placed outside the car for the measurement. Fig. 7 shows the $PM10$ pollution level from this experiment.

Fig. 7. Heat map for $PM10$ pollution

Points are mapped according to their AQI calculated with the formula used by the $AQMC$:

$$AQI = \frac{PollutionValueFromSensor}{PollutionStandard} \times 100$$

The $PollutionStandard$ is defined according the air quality standards of a particulars region. For example, the pollution standard for PM_10 in Senegal is $260\mu g/m^3$ defined by the Senegalese national standard $NS-05-62$ [6]. For each measurement point, the corresponding AQI is calculated, which is the color variation in the city heat map. Following AQI classes defined by AQMC, the air quality is divided into four categories. An index values within $[1, 100]$ exhibits a clean air, [101, 125] represents light pollution, [126, 150] significant pollution and above 150 means heavy pollution. During these tests, we measured more air pollution at the roundabout. The obtained results exhibit the fact that a high traffic density is correlated with high pollution level.

2) Fixed kit measurement: Colobane market within Dakar city has heavy traffic during rush hours. Colobane area urgently requires an air quality monitoring system. We set up a test of our measurement kit in Colobane roundabout as illustrated in Fig. 8). This measurement kit was fixed as landmark during half a day. The obtained results are shown in Fig. 9 and Fig. 10.

According to Fig. 9, the fixed threshold provided by the Senegalese standard ($260\mu g/m^3$) is largely exceeded during half a day of measurement.

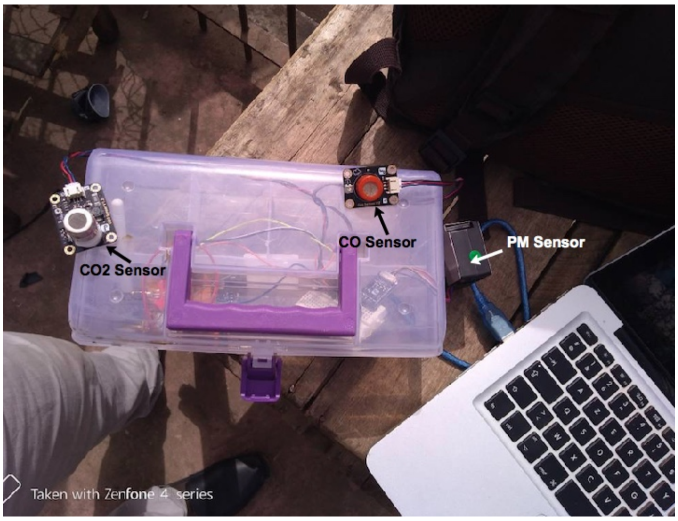

Fig. 8. Test with fixed measurement

Fig. 10 represents the variation of $PM2.5$ with respect to Colobane roundabout district. The depicted values in this graph are above the threshold defined by WHO $(25\mu g/m^3)$.

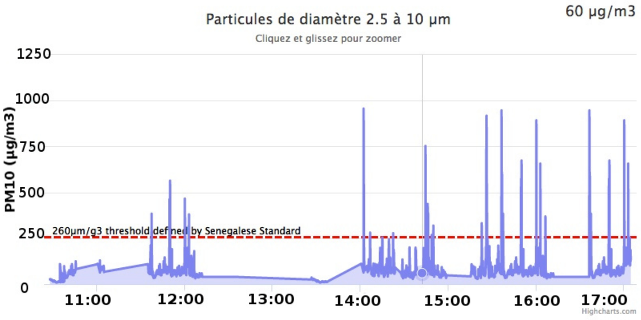

Fig. 9. $PM10$ pollution graph

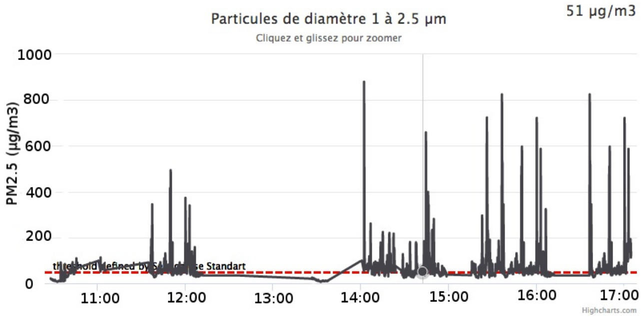

Fig. 10. $PM2.5$ Pollution graph

We noticed three peaks in Fig. 10 according to rush hours ($10am$ to $12am$, $2pm$ to $4pm$ and $4:30pm$ to $6pm$). During these period , road traffic is very dense in Colobane roundabout. In other word, the traffic flow in Colobane market generates more serious air pollution during the rush hours. This shows that increasing the air particles concentration is influenced by road traffic.

V. CONCLUSION

We designed and deployed a hybrid measurement kit. This kit uses wireless sensor network technologies to monitor air quality in real time. The considered measurement kit can be fixed as landmark or embedded in a given car in motion. Furthermore, collected data is transmitted to a web platform for visualization.

Indeed, our obtained dataset can be exploited by different applications. Besides, patients with respiratory or cardiovascular diseases can use our web platform helpful in determining less polluted road. Our system is able to enhance information system informed about the extent of pollution and can motivate to follow better driving patterns, such as not idling for long periods or driving more environmentally friendly cars.

We plan to investigate a large scale deployment. Therefore we need to figure out the optimal geographic position of measurement kits. As well, we aim to improve our system by taking into account other pollutant sensors such as ozone, nitroxide of nitrogen, sulfur oxide.

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