A Survey on Distributed Greenhouse Gases Monitoring Systems

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***Abstract*—Monitoring of air quality represents a major task, due to the direct impact of pollution on human health. Pollution has been further aggravated by the progresses that have taken place in the last decades: traffic growth, traffic noise in cities and growth of urban areas, rising cities, increased energy consumption, industrialization, and economic development. Global warming and acid rain are the results of these factors; thus, air quality is essential to be monitored. This survey presents a set of researches and applications related to air quality monitoring, aimed to detect, measure, collect and process data aggregated from sensors, such as gas sensors for sensing concentration of gases such as CO_2 (Carbon dioxide), relative humidity, temperature, TVOC (Total Volatile Organic Compounds), PM (particulate matter) and noise level. Based on some processes, users will be able to see the polluted areas on the map. The paper presents a state of the art of air monitoring systems, noise monitoring systems, air pollution systems. Also, the paper proposes a distributed greenhouse monitoring system for pollution measurement and control.**

Keywords—Air quality; air monitoring systems; noise monitoring systems; air pollution systems

I. Introduction

Indoor and outdoor air quality represents one of the major problems in the world. Indoor air quality is a very important issue in our life because we spend over 80% of time inside. Obviously, outdoor air quality is even important. So, this is the reason to understand that we inspire about 12000 liters of air every day, and we are exposed to dust, viruses, smoke, pollen, bacteria and other compounds present in the air. It is important to pay attention to the place and time we spend in the locations where symptoms occur.

The results of more than 154 studies carried out in 37 countries by the World Health Organization [1] show that indoor air is eight times more polluted than outside.

Nowadays, it can be seen as a continuous evolution of technology, intense traffic, rapid urbanization that have a significant impact on society as it contributes to the increase in the amount of polluting emissions. Thus, air quality must be monitored permanently, and any unusual values should be corrected with the optimal solution.

In the last decades, a set of organizations, such as EEA [2], EPA [3] in the USA, and NAQMN [4] in Romania, has been created with the aim to monitor and protect the environment. These organizations have set up their own network of stations in order to monitor the characteristics of the air (concentrations of the main air pollutants: nitrogen oxides (NO_x), sulfur dioxide (SO_2), tropospheric ozone, carbon monoxide (CO), particulate matter (PM_{10} and $PM_{2.5}$), polycyclic aromatic hydrocarbons (PAHs), heavy metals such as cadmium (Cd), lead (Pb), nickel (Ni), mercury (Hg) and arsenic(As)). Usually the results of monitoring processes are presented on online platform. According to the characteristic air measurements [5] carried out by these stations, the monitored parameters can be divided into two categories:

- Physical: temperature, humidity, air pressure, wind direction, and speed;
- Chemicals: air pollutants such as ozone (O3), NO_2, CO, SO_2, PM_{10}, $PM_{2.5,}$ and CO_2.

Chemical components are considered by almost all the environmental organizations to be the most harmful to health, due to their respiratory symptoms, decreased lung function, lung inflammation, possible lesions of the lungs and premature mortality.

Fine particles, or particles in suspension, are a mixture of solid particles and liquid droplets found in the air. Some particles can be seen with the naked eye: dust, dirt, smoke, soot, and others are so small that they can only be seen with the microscope. These particles are divided into two categories:

- $PM_{2.5}$, fine inhalable particles; their diameter does not exceed 2.5 micrometers;
- PM_{10}, inhalable particles; their diameter does not exceed 10 micrometers.

There are a lot of sources for PM. Some examples of such sources are presented below:

- Indoor: gas and oil heating, air conditioning – especially if the pipes are dirty, fireplaces – it should be well ventilated, furniture – pillows, beds, chairs, wood-burning stoves - toxins resulting from wood-burning;
- Outdoor: fuel emissions, near fires, changes in atmospheric conditions, the outside air, factories, and power plants.

Certain effects may occur shortly after exposure to a pollutant and may be treated (irritation of the eyes, nose, throat, fatigue, headache, dizziness) but unfortunately, other effects occur after longer periods of time and may be fatal (respiratory diseases, heart disease, cancer). Understanding and controlling common indoor pollutants can help reduce the risk of illness.

A major issue of using extensively vehicles with internal combustion engines is the emission of harmful gases. Polluted air is an important problem that affects human health, but it is usually ignored. The measure of contribution to CO_2 and greenhouse effect gasses emission (GHG) and implicitly to air pollution is a very important task. Excessive pollution as well as dust pollution compromise health and lead to serious respiratory and cardiovascular problems. Some elements that lead to excessive pollution of the atmosphere are:

- Intense and crowded traffic: insufficient measures to streamline traffic in cities and lacks in checking emissions and imposing sanctions.
- Industrial pollution: the absence of rigor in industry surveillance and slow upgrading in state-run units.
- Construction deficiency: prolonged infrastructure works without justification and non-application of environmental legislation to public and private yards.
- Deficiency of monitoring: despite some investments, insufficient or inadequate monitoring, display and warning systems.
- Organizational deficiency: the absence of interest, failure of legislation.
- Deficiency of transparency: issues of access to relevant information and communication deficiencies on behalf of the responsible authorities.

The importance of this survey was reflected in the improvement of the air quality and measures taken for reducing the risk of population illness and the efficiency of the urban traffic control in order to reduce the carbon footprint.

The rest of the paper is organized as follows: Section II presents air quality systems and advantages and disadvantages of them; Section III presents the proposed system and the conclusions are presented in Section IV.

II. Related Work

The paper presents a review of the literature based on greenhouse gas emissions. A set of measuring and monitoring air quality systems are taking into account. These systems can be divided into three categories:

A. Air Pollution Systems

IoT (Internet of Things) is a new concept, which interconnects via Internet all objects (mobile devices, portable devices, lighting systems). In fact, IoT is a dynamic global information network consisting of Internet-connected objects, such as radiofrequency identifications, actuators, sensors, as well as smart appliances that are becoming an integrated component of the future Internet. Thus, there are also many devices and applications that measure different pollutants which can be considered as parts of IoT, such as:

- Foobot [6] determines the air quality in real-time and uses the following sensors: $PM_{2.5}$, TVOC, Humidity, and Temperature. It measures VOC, PM2.5, and CO_2 (derived from VOC), temperature and humidity. Available for both iOS (8+) and Android (4+). It is compatible with 2.4GHz Wi-Fi.
- Air Mentor 6 in 1 [7] Indoor pollutant concentration monitor, can detect CO_2, VOC concentrations with CO, $PM_{2.5}$ and PM_{10}, Relative Humidity (RH) and temperature. Easy to connect via Bluetooth – and it is available for both iOS and Android devices. It is portable, and it can also be used in an outdoor environment.
- NETATMO [8] has the following sensors: humidity, air quality, noise, and temperature. Available for both iOS and Android devices.
- Speck [9] detects fine particles from indoor environments, provides information on PM concentration changes, Integrated Wi-Fi, continuously uploading data, users can view real-time data, as well as historical representation, using a computer or mobile device.

The paper presents a solution for collecting, displaying and distributing environmental data based on mobile phones and portable devices.

B. Noise Monitoring Systems

In [10] a CyberGIS (a new generation of Geographic Information System) designed to facilitate volunteer participation in monitoring urban pollution using mobile devices is described. Cybernetic infrastructure and toolkits facilitate the development of applications that require access to computing and distributed resources. This framework allows scalable data management, analysis and viewing for data collected from mobile devices. To demonstrate its functionality, it focuses on noise mapping. This framework integrates a MongoDB2 cluster for data storage, a MapReduce for extracting and aggregating noise data collected and loaded by mobile devices and a parallel kernel smoothing algorithm using the GPU (Graphics Processing Unit) to efficiently create maps noise pollution from the massive collection of recordings. This framework also implements a mobile application for capturing noise and time measurements as users move around in the urban environment.

The map is dynamically generated using the "kernel smoothing" method. This method is used to estimate a continuous surface (e.g. Noise Level) at the observation points. By processing this data, noise mapping is performed along the trajectory of an individual participant.

Author in [11] makes an approach to automatically creating input data for noise simulations and focuses on using 3D methods to present the results of noise simulation caused by road traffic and industrial activities in urban areas. Several standard noise models for industrial and road noise in CityGML have been deployed by expanding NoiseADE (Application Domain Extension) with new objects and attributes in order to standardize input and output data for noise studies and 3D data reconstruction.

The models allow the computing of the level for:

- the noise produced by road traffic: it is necessary to know certain information such as location, building height, traffic flow, percentage distribution of vehicles on the streets (light/heavy vehicles), speed limits, asphalt type, noise barrier information.
- industrial noise: we need to know the type of noise source, operating hours of cars, noise barriers, location of cars, etc.

Author in [12] presents a system for the protection of users' privacy, which is based on cryptographic techniques and cloud computing. There is a general architecture of the system including a cryptographic protocol based on a homographic encryption scheme for mapping data into maps. Noise Tube is a participatory framework for noise pollution, featuring experiments with real and artificial data sets and a demo on a heterogeneous set of commercial cloud providers. Noise Tube allows the creation of noise maps generated from data collected by multiple users without revealing their location.

Key features of NoiseTubePrime include:

- Correctness: Accurate aggregate statistics are calculated using each user's private measurement data while maintaining the confidentiality of the participating users - there is no location/time data that is revealed.
- Cloud services: The outsourcing of NoiseTubePrime to the cloud frees the users from trouble to run their own software agent and maintain permanent access to the Internet. The computing and networking requirements of each software agent are low and are (currently) provided at no cost to the various cloud service.
- Decentralization: The main task of NoiseTube is to decrypt the finalized map of encrypted noise which is the result of distributed cloud computing. Thus, the central workload is much smaller than a scenario in which the entire calculation is performed by a single central server. Therefore, the NoiseTube service calculation is independent of the number of users participating, making NoiseTubePrime a decentralized system theoretically that can be scaled to treat a large number of users.

NoiseTube [13] is a software platform that uses a mobile application and a website. The mobile application uses the combination of the microphone and the built-in GPS receiver to monitor the sound in different locations of a city. The site allows users to see the noise measurements sent by users.

Sound Meter [14] shows the decibel values by measuring the ambient noise and displaying their values in different forms. This application uses the phone's microphone to measure dB and to display the recorded values.

C. *Air Monitoring Systems*

AirCasting [15] is an open-source solution for collecting, displaying and sharing health and environment data using a smartphone. The platform is made up of portable sensors that detect environmental shifts, including an air quality monitor, called AirBeam, an Android application called AirCasting and portable LED accessories.

AirBeam uses a light dispersion method to measure fine particles or $PM_{2.5.}$ Air is pulled through a detection chamber where the light from an LED bulb shakes particles from the airflow. This light dispersion is recorded by a detector and transformed into a measurement that estimates the number of particles in the air. This is important because the US Environmental Protection Agency monitors and control six air pollutant criteria, one of which is $PM_{2.5.}$ EPA measurements indicate that $PM_{2.5}$ levels represent substantial health risks in cities across the country.

AirBeam measurements are sent once a second to AirCasting Android via Bluetooth, maps and graphs are being displayed in real-time on the smartphone. At the end of each AirCasting session, the collected data is sent to the AirCasting site, where data is collected from different AirCasters in order to generate thermal maps indicating where the $PM_{2.5}$ concentrations are highest and lowest.

AirCasting Luminescent devices connect to AirCasting via Bluetooth and are designed to illuminate the LEDs in response to AirCasting sensor measurements: green for low intensity, then yellow, then orange and high-intensity red. So far models for two luminescent accessories are released: AirCasting Luminescent Vest and LiteBeam. AirCasting Luminescence has been developed to communicate sensor measurements without normally referring to a screen interface and triggering the interaction between AirCasters and people in their immediate proximity.

AirBeam is just an instrument among dozens of people able to transmit data to the AirCasting platform. There is already a flourishing ecosystem of AirCasting compatible tools - some created by manufacturers, others by consumer electronics companies - that can connect to the AirCasting Android application to record health and environment data, including but not limited to:

- Sound levels recorded by the phone microphone;
- Temperature, humidity, concentrations of CO and NO_2 recorded by the air monitor;
- Cardiac rhythm, heart rate variability, R to R, breathing rate, activity level, peak acceleration and core temperatures recorded by Zephyr BioHarness 3;
- Measurements of heart rate recorded by Zephyr HxM.

AirVisual [16] provides real-time data on air pollution and weather meteorological data for more than 6,000 cities around the world, by live monitoring of six pollutants: real-time monitoring of concentrations of $PM_{2.5}$, PM_{10}, ozone, NO_2, $SO_{2,}$ and CO. The application allows users to view air quality in over 9,000 locations worldwide.

SmartAir PM2.5 developed by Thermo Fisher Scientific is the application for pDR-1500 (Personal Aerosol Monitoring). The pDR-1500 [17] is a very sensitive non-photometric (photometric) device whose light diffusion detection configuration has been optimized to measure the respirable dust fraction in air, smoke, and vapor. It measures $PM_{2.5}$ in real-time and can compare the results with outdoor air. It also presents a chart of intuitive lines in 24 hours/week/month representation. Computer requirements: Compatible PC, processor 486 or higher; Windows ™ 95 or later.

D. Discussions

As a result of the study carried out, can be noticed that there are mobile devices and applications for measuring, monitoring and interpreting indoor pollutant data. A summary of the systems is presented in the following Table I.

From the energy consumption point of view, the optimal system is AirMentor, because it is the only one using Bluetooth Low Energy (BLE), which is a portable device and can be used indoor and outdoor, but a disadvantage is that it does not measure noise. From the measured parameters point of view, the best system is Speck, and in terms of reduced dimensions the best system can be considered to be Netatmo.

In conclusion, none of the presented indoor systems can cover all the parameters required (including the noise sensor). Also, none of the presented systems have small size and only AirMentor uses BLE.

Outdoor pollutant measurement applications are presented in the Table II.

TABLE. I. INDOOR SYSTEMS

	Summary of indoor systems			
	Foobot	***AirMentor***	***NETATMO***	***Speck***
Size [inch]	6.69x2.75	4.2x1.8x4.5	1.77x1.77x6.1	4.5x3.5x3.7
Noise			x	
Temperature	x	x	x	x
Relative humidity	x	x	x	x
$PM_{2.5}$	x	x		x
PM_{10}				x
VOC	x	x		
Power		5-1 A		5V
Wi-fi	x		x	x
Bluetooth		BLE		

TABLE. II. OUTDOOR SYSTEMS

		Summary of outdoor systems				
		Air Mentor	***AirVisual***	***Smart Air***	***Noise Tube***	***Air Beam***
Weather Forecast			x			
Noise					x	
Temperature		x	x			x
Relative humidity		x	x			x
CO		x	x			x
CO2		x	x			
SO2			x			
NO2						x
PM	2.5	x		x		x
	10	x				
Bluetooth		BLE				BLE

Among the outdoor systems, the better system is AirMentor, as it covers a large part of the required parameters and uses BLE. Compared with AirBeam, AirMentor measures PM_{10} and CO_2.

The system proposed in the last paragraph of the paper cover all the air quality parameters that use BLE and can be used in indoor and outdoor environments.

III. PROPOSED IDEA

Based on the research presented in Section II, the paper proposes a system which is divided into two subsystems:

A. Indoor

Compared with the previously presented systems, the proposed system uses the beacon shown in [18] and noise measurement sensors are added. The client-server application will allow notifying the user when measured values exceed the normal limits.

B. Outdoor

The main objective of the proposed system is to minimize the carbon footprint. Certain areas have increased pollution every day, at the same time interval (morning between 7:30 and 10:00 when people go to work and in the evening between 15:00 and 20:00 when people return home). Therefore, the GHG concentration depends on the number and speed of the cars traveling through the targeted areas. If the system achieves its goal, it will lead to reducing greenhouse gas emissions and will decrease the negative effects on the population health. An important asset of this system is a solution to decongest traffic in large cities, especially in peak hours when traffic is intense and, moreover, in areas where high-rise buildings are located because they prevent gas dispersion. Using this solution, decongesting traffic directly leads to the minimization of greenhouse gases. A description of the proposed system functionality can be seen in Fig. 1.

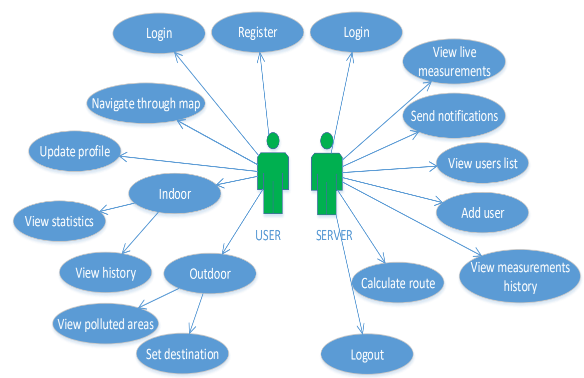

Fig. 1. Use Case Diagram.

The system has a client-server architecture. On the client-side, a mobile application allows the user to do the following actions: register to the application, login, navigate through map, update profile. The user can select indoor display, which shows the statistics and history of measured data or outdoor display, in order to see the polluted areas. Also, if the user wants to travel from the current position to another, the destination can be set. For the server-side, a web application with the following features is implemented: login, view live measurements, send notification (the server will send a warning message to the user when certain measured parameter values exceed the threshold limits), view user list (all users are stored in the database), add user, view measurements history and calculate route (depending on the destination chosen by the user, the server will calculate an optimal route so as to avoid areas with instantaneous measurements of high pollution).

Thus, the traffic in a city or in a specified geographic area can be monitored in real-time, reported to the central server and controlled, in order to reduce the pollution if it increases over some accepted values. Control of traffic avoids the development of highly polluted areas and decreases the greenhouse gas footprint and the noise intensity to acceptable levels. That extends and makes more feasible and useful traffic control with respect to the pollution level compared to the existing systems which use fixed sensors buried in the tread, already implemented on some highways (such as IGL control in Austria).

IV. Conclusions

The main objective of this survey was to emphasize a state of the art in air quality domain and to propose a new system for monitoring a control air quality. Some indoor and outdoor monitoring systems were presented. Also, a comparison was made between the air quality systems, as can be seen from Table I and Table II.

Based on this research, the best-found system is AirMentor, but the paper proposes a better solution that uses smaller dimensions beacon compared with AirMentor. After adding the noise sensor, a complete system can be developed.

The vast technological developments in wireless communication technology have led to the emergence of many pollution monitoring sensors and wireless networks for monitoring and reporting pollution. This information could be used to take necessary action such as emergency warning messages and evacuation of people from problematic spaces.

These systems are designed to measure the parameters of pollutants that can affect people's health, especially in small spaces.

Due to the increasingly crowded traffic and the carbon dioxide emitted by vehicles that have internal combustion engines and emit harmful gases for our health, we need to take measures to streamline city traffic.

The second factor of pollution is traffic noise. The effects of exposure to motors sound are stress, insomnia, cardiovascular disease, and stroke.

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