Mobile Sensors in Air Pollution Measurement

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***Abstract*—In this paper we present a mobile system for air quality and pollution measurement suited for the urban environment. We designed, tested and built a reliable measurement device that can acquire information about the air quality of its surroundings, store it in a temporary memory buffer and periodically relay it to a central on-line repository. Real-time gathered data can be freely accessed by the public through an on-line web interface. Users can select and view different gases and concentrations overlapped on a map of the city.**

***Keywords*-Air Pollution Monitoring, GIS, Geographical Positioning Systems, Microcontrollers, Embedded Systems**

I. Introduction

One of the major environmental concerns of our time is air pollution. Apart from severely degrading the natural environment, air pollution directly affects our health. Short term and long term effects range from light allergic reactions - irritation of the nose, throat and eyes - to serious conditions like bronchitis, pneumonia, aggravated asthma, lung and heart diseases. Air pollution is also the cause of many premature deaths (50,000 to 100,000 deaths per year in the U.S. alone, 300,000 in the EU and over 3,000,000 worldwide [16; 7; 8].

We propose a system that provides live access information about air quality in crowded urban areas such as crossroads or highways. The goal is to monitor the air quality by designing a system that can actively pinpoint pollution sources and polluted areas in traffic.

The solution offered by our system relies on a portable device that can detect an abnormally high concentration of an air pollutant. The device records the measured data along with location coordinates and can periodically transfer it to a computer through a wireless GPRS connection. With the user's acceptance, the application can share the data that will be displayed on a dedicated web site. As a result, the system's user - and the entire community - can benefit from a potentially wide information-gathering network.

Probably the best approach to solving the environmental problems caused by air pollution is to make people aware of it and of their actions that possibly favor it. Our system does just that by gathering and publishing meaningful and up-to-date information. This is the result of people using our devices and sharing the measured data.

Some sources of information on air pollution already exist and are publicly available [12; 15; 11]. However, they do not cover the entire monitored area as they are based on measurements performed at fixed locations. Thus, it is not easy to discover localized pollution sources. Our system has the potential of collecting much more data than a traditional one due to its multi-agent architecture. The more users in the system, the larger the area covered will be and better granularity. In addition, our devices could be installed on public transportation vehicles in order to provide an accurate overview of the pollution generated by traffic.

II. Air Quality

Engine exhaust consists of various gases and particulate emission, which in turn consist of various inorganic and organic compounds with great molecular weight. Their composition depends on driving condition, engine type, gas emission controller, operational temperature, and other factors, all of which make the emission pattern more complicated. The type of pollutant emitted by the engine fueled with gasoline compared to the one fueled with diesel is similar; the difference is in its proportion because of differences in engine operation.

Although engine exhaust gas consists of harmless compounds such as nitrogen, carbon dioxide, and water vapour, it also contains chemical compounds that are harmful to humans and to the environment alike. These compounds are carbon monoxide (CO), various hydrocarbon compounds, various oxides of nitrogen (NO_x), oxides of sulphur (SO_x), and dust particles including lead (Pb). Here are the reasons why our Mobile Unit sensors cover the above-mentioned compounds:

- Carbon Monoxide (CO) This is produced when the fuel in the engine does not burn properly. Road traffic produces 91% of all CO emissions. Problems caused: When inhaled it reduces the oxygen carrying capacity of one's blood and can cause headaches, fatigue, stress, respiratory problems and at high levels - death.

- Nitrogen Oxides (NO_x) These are produced from the burning of fuel in the engine. Road traffic is responsible for 49% of all NO_x emissions. Problems caused: NO_x emissions help to make 'acid rain'. They also combine with hydrocarbons to form low level ozone pollution and may contribute to lung disease.
- Hydrocarbons (HC) These are compounds of hydrogen and carbon and are present in petrol and diesel. Benzene is an example. Road traffic is responsible for about 35% of all HC emissions. Problems caused: Hydrocarbon emissions are carcinogenic and a major ingredient of smog.

Bearing all these aspects into mind, it comes as a consequence that our sensors measure these pollutant factors right from the emission source. The data gathered must on the one hand be compared to the admitted levels (in Europe, there is the Euro standard) and on the other hand recorded locally onto the vehicle itself. A bare 256 MB non-volatile memory card suited on each Mobile Unit can record for as much as several years' emissions log.

III. System Overview

Our system is comprised two major components:

- a car client, called Mobile Unit
- an on-line web server

A. The Mobile Unit

The Mobile Unit, or MU, is entrusted with harvesting the information from the sensors enclosed; the parameters are: combustible gas, carbon monoxide, temperature, air contaminants and gasoline / diesel exhaust. The various parameter levels are transmitted by a GSM link to the web server and displayed live on a liquid crystal display.

B. The On-line Web Server

Provides user access to pollution statistics. It queries the database and reveals the information gathered at a certain time of day in a specific location. Multiple recordings of geographical locations that are in close time and space proximity are averaged. As a consequence, there is a tighter control over mobile sources of pollution which until now, could not be managed remotely.

IV. Mobile Unit Design

The Mobile Unit has been designed and built according to the project's specifications. Being a mobile device, meant to be embedded onto a car, it relies solely on the car's power supply. The entire system can be easily included into the car's onboard computer, and the live information on polluting parameters could be provided to the driver through the dashboard display. As it is built to measure exhaust gas concentration, the Mobile Unit will be powered up only when the engine of the car is running.

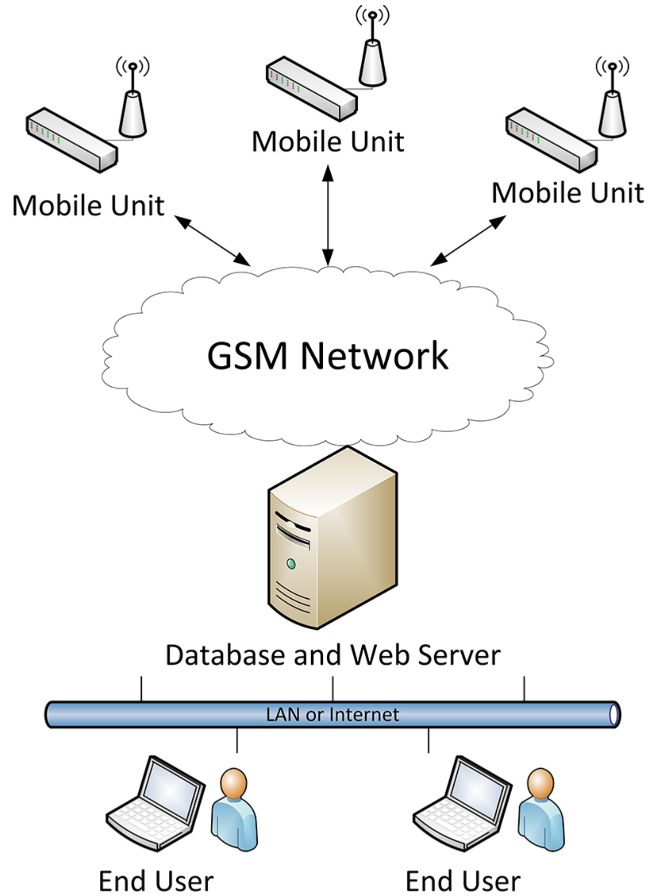

Figure 1. Overview of the information flow in the system.

The device must be exposed to a clear airflow so that it can properly take readings. In order to fulfill this requirement the sensors are placed in a separate case which can be attached to the outside chassis of the vehicle using magnetic clips.

1) The Main Module: The Main Module is a control unit that implements the functionality of the device. It is build around a microcontroller and its main purposes are:

- control the data acquisition from the sensors
- record and store the data measured by the sensors
- display sensor data in a graphical form on the LCD display
- direct the communication between the device and the data server over the GPRS data link

2) The Data Acquisition Module: This module measures the concentrations of different gases and converts them to a format understood by the main module. Because uniform access to the sensors was required, the module has a Sensor Interface. The device is equiped with three sensor slots that can accommodate various sensors. One of the most

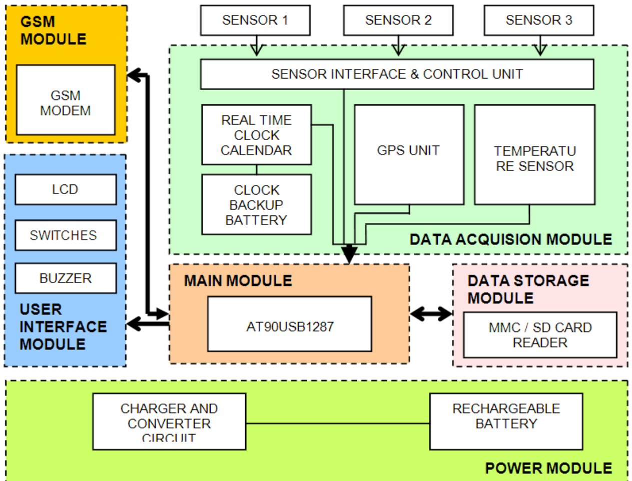

Figure 2. Mobile Unit hardware diagram.

important aspects of the device is the fact that the sensors are pluggable: the user can select from various types of sensors the ones that are most relevant to his situation and plug them into the device. A list of sensors that our device currently supports and the associated health threats includes sensors for the following pollutants:

- Carbon monoxide - generated by incomplete combustion of carbon - even relatively small amounts of it can lead to hypoxic injury, neurological damage, and possibly death [9];
- Ammonia - one of the most widespread gases - children with asthma may be particularly sensitive to ammonia fumes; also a significant part of respiratory allergies are related to this gas and prolonged exposure to ammonia may cause nasopharyngeal and tracheal burns, bronchiolar and alveolar edema, and airway destruction resulting in respiratory distress or failure [1; 2];
- Hydrogen sulfide - generated by bacteria as part of organic material decomposing - can cause asthma attacks, eye, throat and lung irritation, nausea, headache, nasal blockage, sleeping difficulties, weight loss and chest pain [3].
- Gasoline and diesel exhaust - major pollutants of populated areas - exposure to this mixture may result in asthma attacks, increase likelihood of cancer, chronic exacerbation of asthma and other health problems [4].
- Natural gas, propane, methane and other petroleum derivative gases - essentially fossil fuels - that can cause irritations to the upper respiratory tract or, in contact to a source of heat, can provoke fires and explosions.
- Carbon dioxide and general indoor pollutants - generated by a multitude of human activity - indirectly increase the likelihood of asthma attacks and may cause a rise in asthma cases among children [5].

Thick film metal oxide semi-conductor sensors from Figaro [6] were the preferred choice for our system, because of their good sensitivity to target gases, simple interface circuitry, low cost and long life.

Because the sensors' output values depend on the temperature of the environment, a temperature sensor is used to obtain this information and adjust measured values accordingly.

Gas Type	Measurement Range	Sensitivity	Response Time
CO_2	$350 - 10,000ppm$	$350ppm$	$1.5min$
NO_x	$0.1 - 10ppm$	$0.3ppm$	$30s$
CO, HC	$10 - 1,000ppm$	$10ppm$	$30s$
NH_4	$30 - 300ppm$	$50ppm$	$2min$

Table I
GAS SENSOR SPECIFICATIONS

In order to provide an accurate description of the pollutant agents' situation in a geographical area, the device is equipped with a GPS module that has an embedded antenna.

When GPS connectivity is available, the records will have the current geographical coordinates marked. When the GPS signal is blocked, the geographical locations for the records are interpolated based on the coordinates immediately before and after the hiatus. For performance considerations, the system performs the interpolation in the on-line application.

Along with the geographical coordinates and the recorded values of the pollutant gases, the time and date of the data acquisition must be recorded. This is done by a real-time clock chip. The module also contains a backup battery. When the device is on, the main power module powers the clock chip. If the power module is unavailable, the backup battery takes up the power supply function. The internal clock is synchronized with the real-time clock of the GPS whenever a GPS connection is available.

3) The Data Storage Module: One of the requirements for the Mobile Unit is to store the measured data together with contextual information such as geographical coordinates and time. We have installed a SD Card Interface, which allows the connection of any commercially available memory card, thus providing the device with virtually infinite storage space. The Serial Peripheral Interface (SPI) protocol is used to address the memory.

4) The User Interface Module: This module provides a way for the device to display real-time measurements from the sensors and GPS module. It also displays information about GSM connectivity and can signal if certain air pollutant values have crossed a preset threshold.

5) The GSM Module: The GSM Module serves as an interface between the device and the PC. It is built around a WAVECOM dual band GSM/GPRS modem that can stream sensor data over the existing cellular network.

6) The Power Module: The power source is a 3.6V Li-Ion cell mobile phone battery. All of the electronic devices

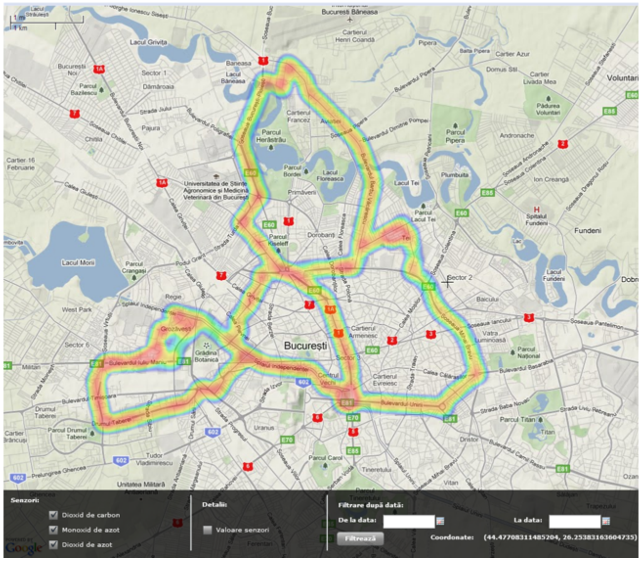

Figure 3. Web interface showing air pollution along some of Bucharest's busiest streets.

are powered directly from the battery. The sensors, however, require a 5V power supply. A DC-DC converter is used to achieve this. The module also has a circuit that can recharge the depleted battery from an external DC adapter.

V. Software Design

The software development for our system is split into two parts - the Mobile Unit firmware and the Data Server. On the Mobile Unit side, the software was developed in C, using the WinAVR compiler suite for AVR microcontrollers. The server side was developed using Flex for the web interface and MySQL for the database that stores sensor and location data.

A. Mobile Unit

The microcontroller periodically reads sensor data and stores it in the flash memory along with the positioning data and time stamp from the GPS module. Sensor data is also displayed on the Mobile Unit's LCD and the user can select viewing instantaneous values or historical values for each gas type in the form of a data plot. From the system's memory, gathered data is sent via the GSM/GPRS modem to the server once every hour.

B. Data Server

The server is a desktop machine that is permanently connected to the Internet[10] and has a GSM modem attached to its USB port. A special daemon was written to interface the modem to the MySQL database and to handle data calls from multiple Mobile Units. For data visualization, the Flex application queries the database and overlays sensor data on a map of the city, using the Google Maps API.

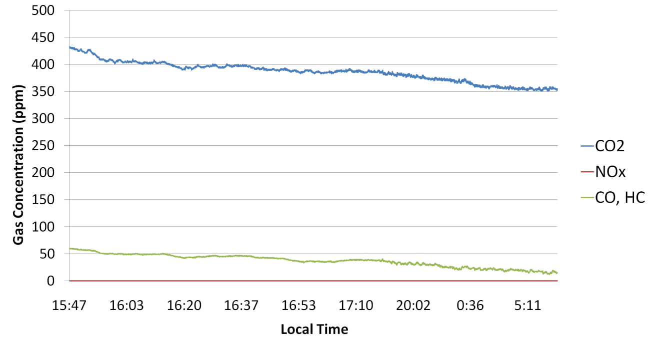

Figure 4. CO_2, NO_x and CO/HC gas concentration variation for a fixed location

Users can browse through the data and display individual gas concentrations or all pollutants at the same time. They can also select specific time periods for the displayed data or zoom in to see individual measurement point values.

VI. Experimental Results

For early prototype testing, we carried static measurements over long periods of time. The Mobile Unit was placed in a fixed position on the rooftop of our faculty building and the sensors were exposed to the atmosphere. We measured variations in CO_2, NO_x and CO/HC gas concentration over the course of twelve hours. These values were compared to expected normal values that occur during daily cycles [14; 13].

Our measurements reveal that NO_x concentrations were very small and stable around $0.05ppm$. Also, we found that CO_2 gas concentration varies during the day-night cycle, dropping in value from around 430ppm in the afternoon to 350ppm early in the morning.

CO and hydrocarbon gas emissions are almost at a constant value throughout the period, seeming to drop in the early hours of the morning. This appears to be correlated to the decrease in vehicle traffic during the night.

Mobile system testing in traffic was done by installing the Mobile Unit prototype on a privately owned car and driving around a predetermined path in the city of Bucharest. In order to view the changes in air pollution, measurement sessions were made on the same course but at different times of day, both during high traffic hours in the morning and afternoon and with little or no road traffic, late at night.

One example of higher than normal air pollutant concentration can be seen in Figure 5. The web page accurately shows an increase in pollution in "Unirii" area, which is a square situated at the convergence of five of the city's major road traffic arteries.

VII. Conclusions

Our prototype implementation of the hardware and software proves that the concept is a viable solution for air pollution monitoring. It is not universally applicable, as it

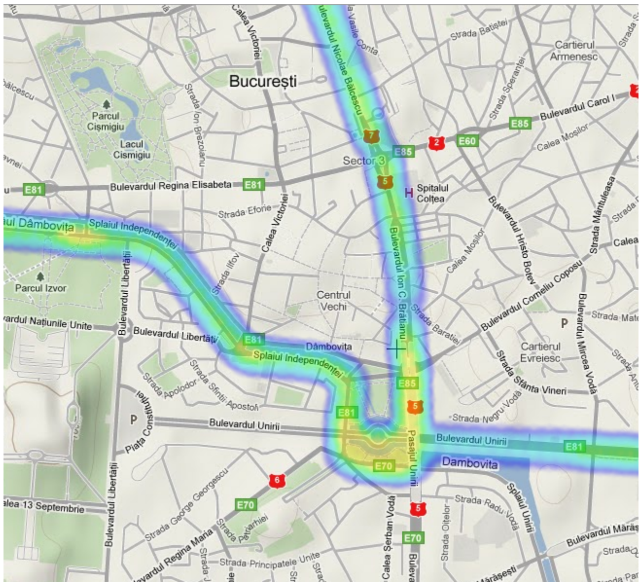

Figure 5. Web page extract showing air pollutant concentrations

only measures pollution in the areas where people live (most of the times these are the most polluted areas). However, this is exactly its intended purpose: to provide relevant information about the areas people are actually interested in.

Many people will immediately benefit from our system: asthmatics, people concerned about the air quality, joggers, etc. On the long term, government agencies that regulate and impose pollution standards can benefit from the large amounts of data gathered by our system which can result in better statistics and understanding of the way pollutants affect the urban environment. It can also lead to better air quality management and to pinpoint major pollution sources inside of a city.

Due to its modular design, our system can be extended to offer additional functionality. For instance, multiple Mobile Units could be installed on public transportation buses and trams, offering an up-to-date and detailed picture of urban pollution. Furthermore, it could use the location tracking capabilities of the mobile telephony networks instead of the GPS system.

More complex logic could be incorporated in the server application, allowing the automated identification of problem areas and possibly the prediction of air pollution patterns and expansion, based on meteorological data.

VIII. Acknowledgements

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