Low-cost Air Quality System for Urban Area Monitoring

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***Abstract*—With the worldwide urban population following a continuous growth, more individuals expose themselves to a less healthy environment by inhaling polluted urban air. The current pollution measurement techniques make use of automated monitoring stations that are usually installed in certain key points around the city but can only provide coarse-grained air quality reports as well as not being able to indicate the sources of the air polluting agents. As traffic related air pollution cannot be traced to a single location, there is the need for a new approach which has the capacity of measuring fine-grained air quality that can reflect any detailed variations that may be caused by traffic jams. In this paper, we intend to offer a solution by implementing a low-cost air quality system using mobile sensing for monitoring the variance of gaseous pollutants in metropolitan areas.**

Keywords—Urban Air Pollution; Mobile Sensing; Air Quality; crowd-sourcing; Participatory Sensing; Pollution;

I. INTRODUCTION

With more than 50% of the world's population living in urban areas, and a high chance that this number will increase to 70% by 2050 [1], the World Health Organization (WHO) estimates that over two million people die every year from air pollution, more than half of them living in developing countries [2], and nearly 1.4 billion people worldwide live in urban areas with air pollution above recommended air quality limits [3]. The consequences that pollution has on the air quality is of both scientific and social interest, especially to countries with rapidly developing economies where the exposure to concentrations of airborne pollutants has been shown to cause negative health effects in both the short and long term [4].

In the developed countries, urban air pollution originates mostly from the burning of fossil fuels from vehicles engines, with this being the most significant source of exposure for individuals, thereby affecting not only the environment, but also having considerable effects on the health of the population. There have been studies that have found evidence of the negative effects that exposure to ambient gaseous pollutants and particulate matter has on an individual's health, including the aggravation of asthma, cardiovascular morbidity, various cancers, birth outcomes and life expectancy [5, 6, 7]. Outdoor air pollution has disproportionate health effects on infants, children, elders or people with pre-existing health conditions [4].

According to the Romanian National Environment Protection Agency (ANPM), the six most common pollutants that affect air quality are sulfur dioxide (SO_2), nitrogen oxides (NO_x: NO/NO_2), ground-level ozone (O_3), carbon monoxide (CO), particulate matter (PM10, PM2.5), lead and other toxic metals like cadmium, arsenic or mercury [8].

Particulate matter is composed of tiny particles of solids and liquids including ash, mineral salts or oxides, heavy metals such as lead, and other organic materials [9], and is characterized by its particle size, either PM10 (diameter ≤ 10 microns) or PM2.5 (diameter ≤ 2.5 microns). Nitrogen oxides, sulfur dioxides and carbon monoxide are produced by the combustion of fossil fuels, and have a major effect on creating acid rain and photochemical smog, which is a phenomenon that forms when carbon monoxide or nitrogen dioxide reacts with sunlight to create secondary pollutants.

According to the most recent census, approximately 52% of the total of twenty million Romanians live in towns and cities, with a 1.3% growth every ten years [10]. Almost two million people live in the capital city of Bucharest where more than 90% of air pollutants come from intense road traffic, and where around one hundred thousand new vehicles are registered every year. Around 74.1% of nitrogen dioxide and sulfur dioxide are emitted from the power plants that are scattered around the city [11]. A survey from 2011 that involved twenty-five European cities found that Bucharest has the lowest urban air quality, with a concentration of 38.2 micrograms of fine particles per cubic meter of breathable air, lowering the average life expectancy with almost two years, where other European capitals like Rome, Paris or London have concentrations of 21.4 $\mu g/m^3$, 16.4 $\mu g/m^3$, respectively 13.1 $\mu g/m^3$ [12].

In Bucharest, ARPMB (Regional Environment Protection Agency Bucharest), an organization tasked by the Romanian government to monitor air quality is operating a network of eight automated monitoring stations scattered around the busiest parts of the capital. ANPM (National Environment

Protection Agency), theoretically makes this information available online in real-time [13], but practically only the previous day data is accessible with partial information about the current day. An in-depth analysis made in 2011 by a non-governmental organization called Ecopolis found that 23.4% of the data recorded by the eight monitoring stations throughout one year are invalid or are completely missing, either because the monitoring stations were unexpectedly shut down, or have provided invalid measurements [14].

This paper proposes a concept of an air quality monitoring system through mobile sensing using low-cost reliable sensors in order to record the variation of a series of various gaseous pollutants in metropolitan areas. In Chapter III, we present our theoretical model that involves two types of mobile sensing networks, and one stationary network of sensors, and how the final data cam become available online, followed by our first test implementation during the summer of 2014 that is presented in Chapter IV along with the results we obtained, that are presented in Chapter V. Chapter VI provides the further improvements on our implementation which we wish to put into practice in the future. The following chapter offers a brief summary of the current developments of the most recent urban air quality monitoring techniques.

II. RELATED WORK

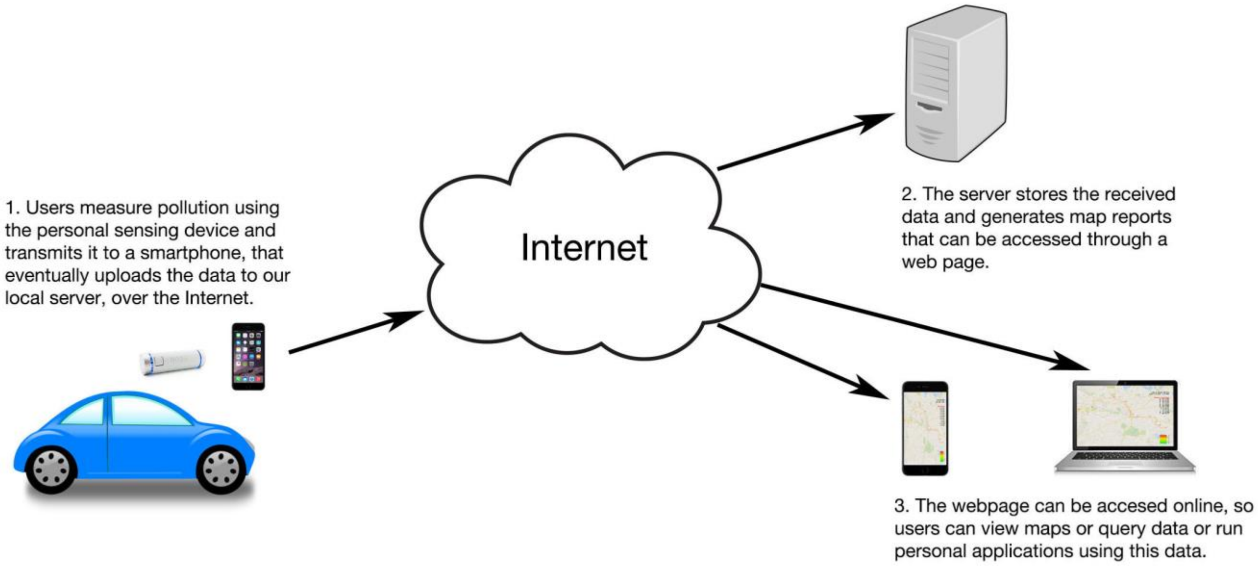
The monitoring of urban air quality through mobile sensing is a popular topic especially with the possible applications of designing, deploying and administrating wireless sensor networks that measure gaseous pollutants from various urban scenarios. The project that has introduced the paradigm of personal pollution-sensing platform was initially developed in 2012 by a community effort of designers, technologists, developers, students and artists. Air Quality Egg grew out of Internet of Things meet-up groups in New York City and Amsterdam, offering anyone a chance to participate in the project [15].

An earlier project with similar vision was MESSAGE (Mobile Environmental Sensing System Across Grid Environments), which started in October 2006 and included researchers from universities of Cambridge, Leeds, Newcastle and Southampton [16]. The project aimed to develop both fixed and mobile devices that would generate a high-density measurement of carbon monoxide and nitrogen oxides in metropolitan areas. In a recent report [17] they demonstrated that the deployment of low cost devices that use electro-chemical sensors can generate an accurate picture of the spatial and temporal structure of air quality in urban areas. Studies on the feasibility of measuring urban air pollution using wireless sensors have been made [18], with other studies analyzing the validation of low-cost instruments for monitoring air quality [19] and other implications.

A similar project that aims to offer a vehicular-based approach for real-time fine-grained measurements of air quality was developed at Rutgers University [20], using the same handheld pollution measurement devices from Variable Technologies that we have used in our implementation.

The Personal Environmental Impact Report (PEIR) [21] proposes a method for accounting personal movement by making use of location data sampled from mobile phones in order to create travel patterns for personal estimates of environmental impact [22].

The CitySense project [23] developed at Harvard University aims to enable users to track personal air quality exposure by making use of an existing wireless distributed sensor network of individually programmable nodes scattered throughout a city, and also create an open *testbed* to support a



1. Users measure pollution using the personal sensing device and transmits it to a smartphone, that eventually uploads the data to our local server, over the Internet.

2. The server stores the received data and generates map reports that can be accessed through a web page.

3. The webpage can be accesed online, so users can view maps or query data or run personal applications using this data.

Fig. 1. Brief description of our system architecture model

diverse range of research activities.

The approach of installing mobile sensing devices on the roofs of buses and trams thus creating a mobile air quality monitoring network using the existing public transportation network has been followed in a project called OpenSense [24], which is run by Ecole Polytechnique Federale de Lausanne in partnership with ETH Zurich. Such an approach has the advantage of offering the possibility of deriving pollution maps with unprecedented spatio-temporal resolution creating a new path towards accurate, real-time pollution assessment.

Common Sense [25], a joint project between UC Berkley and Intel Labs, aims for a complementary mobile participatory sensing approach, in which pollution measurements are made not by using a network of fixed sensors, but by deploying large numbers of personal mobile sensors within communities, thus allowing community members to explore local variations in air quality and engage in a process of locating pollution sources.

III. SYSTEM DESCRIPTION

While we were researching and analyzing which would be the most efficient strategy type that would better suit our implementation, we chose to develop a data collection system based upon the idea of “crowd-sourcing” or “participatory sensing”, in which any user could collect and contribute to an open database of air pollution measurements using the personal sensing device. Offering the opportunity for anyone to use, collect and contribute has an important role in the further development of the project that could create a greater spatial density of data gathered from multiple users from any location.

Our proposed system architecture is described in Fig. 1, and consists of portable personal sensing devices that would normally be attached to a volunteer’s or an user’s car as they drive. The personal sensing devices will communicate with an application on the driver’s mobile phone that gathers the measured data from the sensing device, and then tags it with additional information regarding the GPS coordinates of the location where that data was gathered along with the time and date. Our cloud-based server will receive and store large amounts of information from multiple users as they finish pollution recording sessions and upload the gathered data over the Internet. The server will then parse and interpret that data, applying interpolation models in order to generate a pollution level heat-map and make that map available online on the project’s website. The proposed system architecture model can be separated into two phases, first consisting of data collection and the second representing the data consumption, analysis and graphical representation of the results.

A. *Data collection approach*

When we first took into account the possibility of designing a system to measure urban pollution, we imagined several types of ways in which that could be accomplished. The model presented in Fig.1 uses a “participatory sensing” approach, that could be implemented for mobile sensing, which is what we put into practice and tested, the results will be presented in chapter V. But nonetheless, in order to get a highly accurate estimate of the levels of various atmospheric pollutants in a specific area, or to observe how pollutant emissions flow through the atmosphere, a stationary sensing network shall be developed. Likewise, having decentralized pollution recordings from various locations at different moments in time, obtained from users that do not follow the same route for at least a couple of days cannot lead to the formation of time patterns for pollution, or further observation of the period of time within a day or within a week when pollution might be higher than normal. This problem could be easily solved by implementing a mobile sensing network on the top of an existing public transportation network, thus solving the spatial-time problem by observing pollution recordings from fixed routes throughout the day, making it easier for further predictions or analysis of the flow of air pollutants. In the next two subchapters we will briefly discuss these two different branches.

1. *Personal Sensing Network*

The Personal Sensing Network is a type of sensing network that we propose to implement in our pollution-sensing schema. It is designed around two other sub models that separate the pollution report depending on the type of data recording: stationary or mobile.

The first sub model is developed for measuring the concentration of carbon monoxide in a stationary place. It consists of a single or multiple sensing devices, recording data from different points, thus gathering information from one single area, which makes the measurement more accurate. In this scenario, the data is being flagged as stationary sensing report, and all data that is collected is in synch with each other, making the server interpret all reports under the same flag as one single report. Under the Romanian law [26] for one stationary sensing report to be accepted, the recording of data must be at least forty-five minutes long, for an hourly report. The server will check for this requirement before accepting the data.

The second sub model is designed for measurements made in mobile situations, such as walking or cycling in different areas of a city. It consists of a single device that is carried by a volunteer. The sensing platform is developed as a small, mobile, easy to carry device. It can be either an autonomous device, or connected to the volunteer’s mobile phone through Bluetooth Low-power, using a custom application. In this case, the application will gather data about levels of carbon monoxide concentration, time and GPS location and send them to our server over a cellular data link. In order to make the measurements more accurate, each volunteer will be assigned to a fixed route in order to cover it on a daily basis for a predetermined number of days, thus partially solving the problem described in the beginning of this chapter.

2. *Public Transport Sensing Network*

The Public Transport Sensing Network is a type of sensing network which is designed to use public buses or trains in order to gather data over fixed reliable routes, providing information regarding the flow of carbon monoxide during different times of the day, under different types of road traffic.

For this type of sensing network, the devices will be completely autonomous, similar to the one in the first sub model of the Personal Sensing Network, but adapted for the mobile situation of the public transportation vehicle. In this type of situation, we will have the freedom of packing more sensors per device, rather than just carbon monoxide. The device will record data about the current concentration of pollutants, time and GPS location, and will store the information in a file saved in the flash memory of the device. At the end of the day, the volunteer bus driver or motorman will hand over the device to one of our associates, who will gather the data and upload it to our server. The manual harvesting of data will be initially implemented as a security precaution with a further development for an Internet-of-Things type of network.

B. *Description of the personal sensing device*

As a brief overview, the pollution sensing device uses mobile sensing in order to collect data from remote locations or different situations. Sensors are used to collect information regarding the concentration of carbon monoxide along with other important data, like time, date and GPS coordinates. This data is being stored in a flash memory attached to the device and can be accessed after the recording process is finished, using a mobile application that fetches the file from the device, using Bluetooth connectivity. The collected data is then uploaded to one of our local servers, where it is then processed, and the results are represented by generating a two-axis graph and a heat-map.

In the process of developing the personal sensing device there are several key challenges that need to be confronted in order to get a satisfactory result. There are a lot of factors that need to be taken into consideration, but only a careful selection might lead to a mass adoption of the project. Some of the challenges are summarized below:

Sensors: In order to have a complete pattern of the flow of various urban pollutants, there is the need of developing a device that could gather information about all sorts of gaseous pollutants, therefore each pollutant gas will have a dedicated sensor that would measure its concentration in the given area. For the most common air pollutants such as carbon monoxide (CO) or nitrogen oxide (NO) we implemented a device using Metal Oxide (MO) Sensors. These sensors have a heated semiconductor material that reacts with a specific gaseous pollutant by freeing electrons, therefore decreasing its effective resistance proportional to the level of air pollutant that had entered into the sensor’s chamber. These sensors are cheap [27, 28, 29] but can have critical performance issues when exposed to low or high levels of temperature, pressure, wind or humidity, therefore limiting their effectiveness.

Calibration: In order to have a coherent data recording, the major challenge is calibrating the sensors so that pollutant concentrations are recorded as accurate as possible. For this step we followed the process that Sivaraman, Carrapetta, Hu and Gallego Luxan (2013) [30] have used in their calibration process. Using a custom-built air tight room and a commercial pollutant monitor we submitted both devices to different concentrations of pollutants and therefore created an adjacency between the value read by the pollutant monitor and the ADC read value from our sensors, finally creating a discrete mathematical function that would approximate a given value using these discrete seed values.

Complexity: The final personal sensing device is broadly composed of a small micro-controller equipped with a built-in ADC used to digitize the analog sensor readings, the gas sensors, a Bluetooth Low-power module used to communicate with a phone application, a battery supply and, although our first prototype did not have one, a microSD slot used as flash memory. We determined that if we were to create an autonomous device that would have a built-in GPS module and a 3G GSM module to upload in real-time it would highly increase complexity, so we decided on a design that depended on a mobile phone to get the pollution measurements from the device and tag them with GPS coordinates, time and date, and then upload them over the Internet.

IV. TESTING METHODOLOGY

In order to have an experimental background in the field of mobile sensing while understanding different aspects of urban air flow, we started small, by testing different sensor platforms available on the market. During the first test, we focused on implementing an air quality monitoring system that would initially work in order for us to test the design, while future improvements could be made during the next tests.

Fig. 2. The NODE Wireless Sensor Platform with an OXA module attached

For the purpose of sampling data in order to understand and choose a more accurate way to measure the concentration of gaseous pollutants we tested the NODE Wireless Sensor platform with an OXA module attached, presented in Fig. 2, in order for us to measure the carbon monoxide concentration in various places in Bucharest, for about three weeks, gathering enough data so that we could test the system and draw some conclusions.

The NODE Wireless Sensor platform is a versatile, customizable mobile handheld sensor that uses Bluetooth to interface with a smartphone, in order to transmit the measured pollution levels. The communication between the device and mobile phone is made using an Android application that uses the NODE Android framework in order to discover, connect and establish a communication with the NODE OXA module, and fetch data from the sensor every five seconds, storing all the information in a file stored in the internal memory of the mobile phone. For every sampling, the Android application tags the data with additional information regarding the GPS coordinates, date and the time the sampling was made.

During our sampling tests, we used the OXA module to measure carbon monoxide and an iOS device running N+ Oxa, an application made available by Variable Technologies for collecting data. For location, date and time tracking we used a third party application that ran in parallel with the N+ Oxa application, that generated a location report at every five seconds, along with the date and time of that entry. Finally, using a third application we generated a final report that had every pollution data entry in the file generated by the N+ Oxa application tagged with the appropriate date, time and location where it was recorded.

The final report was then uploaded to our server, where using a simple application written in C++, a two axis graphical representation of the pollution report was generated, along with a heat-map visualization of the pollution throughout the route on which it was observed. In the next chapter we will discuss two of such reports, describing the strategy we used for the data manipulation.

V. RESULTS

During the first three weeks of testing we started deploying the personal sensing device inside the car, which is probably the typical scenario in which any other user might use the personal sensing device. On several occasions we encountered critical increases or decreases of concentration measured while driving with the passenger seat window down, and we assumed that external factors, in this case most probably wind, interfered with the sensor module, affecting the accuracy of the recording. Therefore we continued sampling with all the windows closed and the air conditioning circulating the air inside out.

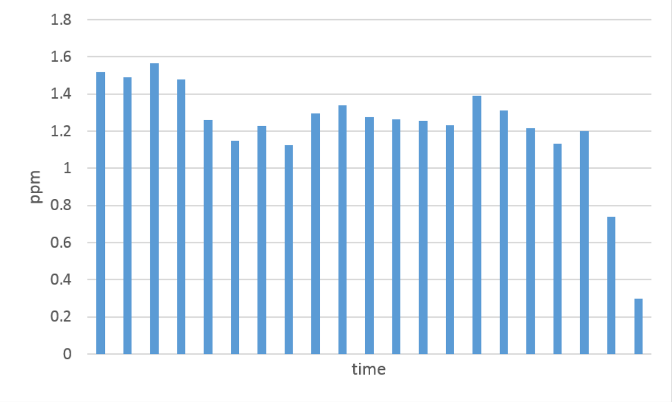


Fig. 3. Graphical representation for the first report of carbon monoxide concentration

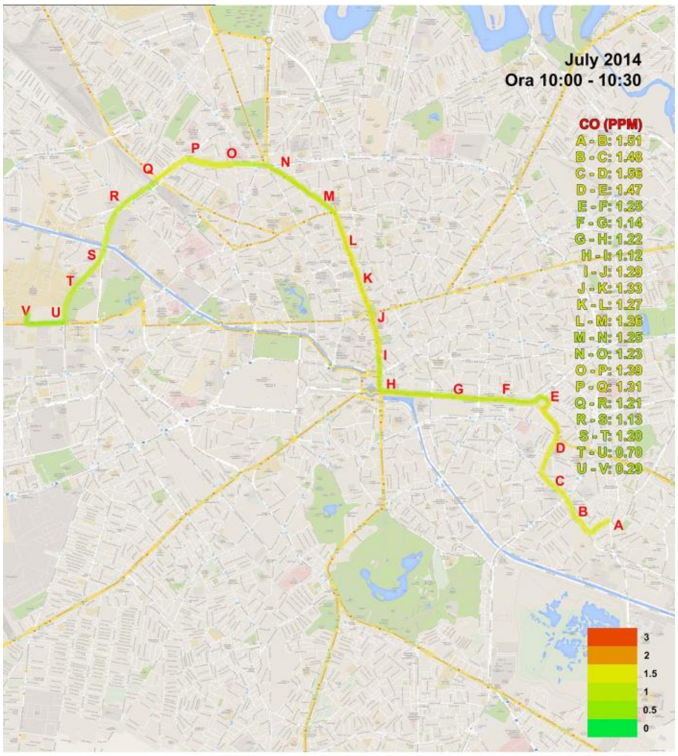


Fig. 4. Heat-map representation for the first report of carbon monoxide concentration

We also tried mounting the personal sensing device outside the car, but after observing incoherent measurements we realized that the sensor had a wind sensibility, thus deciding to continue only with sampling done inside the car. Besides the wind, the exposure to higher of lower temperatures other than an average of twenty to twenty-five degrees Celsius had also affected the sampling process. For example, if the sensing device was held in hand, thus getting in contact with the human body temperature, the values went up accordingly, while on the other hand if exposed to lower temperatures, especially during transition of autumn to winter, the values suddenly went down when it was cold enough, making it a non-reliable report. We believe the reason of this behavior is the use of Metal Oxide Sensors for the OXA module, which have known performance issues, as we described in chapter III.

Before we deployed the sensing device on the inside of a car, we tried using the device to sample data from a pedestrian walk scenario. During all the tests we made, we got lower results than we would have gotten if we were to sample data using a car, thus leading to a possible conclusion that the pollution is different at the sidewalk level than it is at the road level, but this needs further analysis.

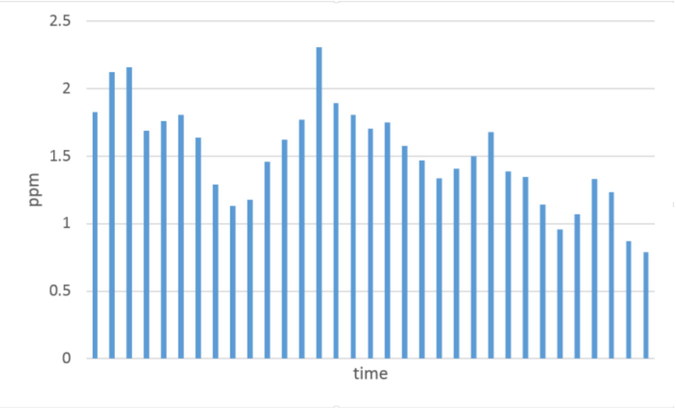


Fig. 5. Graphical representation for the second report of carbon monoxide concentration

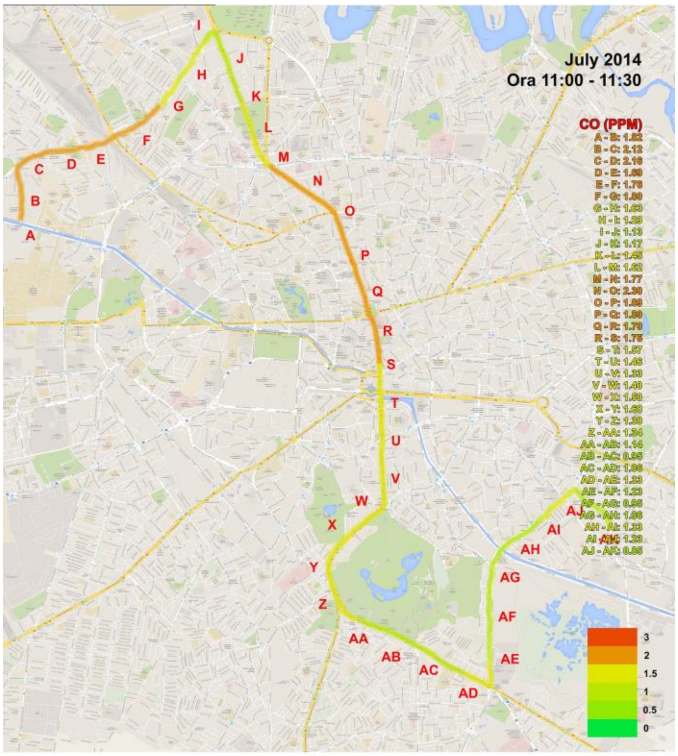


Fig. 6. Heat-map representation for the second report of carbon monoxide concentration

The first pollution report is presented in Fig.3 as a two axis graphical representation of pollution concentration in parts-per-million throughout the time, and in Fig. 4, as a heat-map representation of the concentrations of carbon monoxide measured throughout the route. This report consists of an average of five days of sampling carbon monoxide inside the car, in the morning, on the way to the university. The graphical representation presented in Fig. 3 consists of a number of vertical columns, each representing an average value measured for a period of five hundred meters, thus in case of high traffic there will be more samples to be averaged than in a low traffic situation.

The second pollution report is presented in Fig. 5 and Fig. 6, in a similar manner as the first report. It follows a deviation from the normal route in order to record pollution information from all areas of the city, which can be observed in Fig. 6. Same as with the first report, the two axis graphical representation presented in Fig. 5 represents an average value for a distance of five hundred meters for each vertical column, with the report consisting of an average of four sunny days of measuring carbon monoxide from inside the car, in the afternoon.

VI. FUTURE WORK

The current development aimed to test the theoretical model we have proposed in Chapter III by using an available handheld pollution measurement device and integrate it in our proposed system. Because the current implementation only uses carbon monoxide sensors to measure air quality, an important further development will be the implementation of other sensors for different gaseous pollutants, especially for nitrogen oxides and particulate matter. Given the research we have done for the writing of this paper, we conclude that in the case of studying the flow of air pollutants in the city of Bucharest, the most effective way will be to focus on analyzing the levels of particulate matter and nitrogen oxides.

An important improvement will be the development of our own personal sensing device that would make use of low-cost, well calibrated sensors and better integrate with our model of sensor network. A development of an autonomous wireless network of sensors that could be administered remotely would better suit our stationary monitoring system model.

As for the visual application of the network, the development of a stable, reliable server that would analyze and generate statistics using all the data collected from various sensing devices, either mobile or stationary, represents an important step for the project, thus offering a front-end application that can be accessed and queried by anyone. Developing an open API would provide users access to the entire pollution database and thus offering the chance of creating personal applications that would better use the collected data, making the entire project open and available for anyone to contribute.

REFERENCES

[1] UN Habitat, State of the World's Cities 2008/2009 – Harmonious Cities. Chapter 1.2 Urban Growth Patterns. ISBN: 978-1-132010-7. 2008. Available online at: http://mirror.unhabitat.org/pmss/listItemDetails.aspx?publicationID=2562

[2] World Health Organization (WHO), "Air Quality & Health Questions and Answers". Available online at: http://www.who.int/phe/air_quality_q&a.pdf

[3] World Health Organization (WHO), "Air Pollution". Available online at: http://www.who.int/topics/air_pollution/en/

[4] Top 10 Worst Pollution Problems 2008. Urban Air Quality. pg 29-31. Blacksmith Institute. 2009. Available online at: http://worstpolluted.org/reports/file/World's%20Worst%20Pollution%20Problems%202008.pdf

[5] HEI Pannel of the Health Effects of Traffic-Related Air Pollution: Traffic-related air pollution: a critical review of the literature on emissions, exposure and health effects. Boston, Massachusetts: Special Report 17; 2010

[6] Kampa M., Castanas E., "Human health effects of air pollution". Environ Pollut 2008; 151(2): 362-7

[7] Peters A., Döring A.,Wichmann H., Koenig W., "Increased plasma viscosity during an air pollution episode: a link to mortality?" Lancet 1997; 349(9065):1582-7.

[8] Romanian National Environmental Protection Agency. Air Pollutants (Agenția Națională pentru Protecția Mediului. Poluanți atmosferici) (Romanian). Available online at: http://www.calitateaer.ro/parametri.php

[9] Research Areas: Hazardous Components Research Program: Particulate Matter (PM) Health Effects. Environmental Protection Agency. Last Updated May 2, 2008. Available online at: http://www.epa.gov/NHEERL/research/pm/research_area05.html

[10] 2011 Romanian Census. Defining results (Recensământul populației și al locuințelor 2011. Rezultate definitorii) (Romanian). Available online at: http://www.recensamantromania.ro/wp-content/uploads/2013/07/REZULTATE-DEFINITIVE-RPL_2011.pdf

[11] Article on the report from the Romanian National Environment Protection Agency regarding air quality in Bucharest. (Romanian) Available online at: http://www.hotnews.ro/stiri-mediu-7111975-90-din-poluarea-co2-din-bucuresti-este-cauzata-traficul-rutier.htm

[12] Air pollution in areas of heavy traffic shortens life expectancy. Available online at: http://www.theguardian.com/environment/2011/mar/08/air-pollution-life-expectancy-dupont

[13] Official website made available by the Romanian National Environmental Protection Agency on pollution reports. (Romanian). Available online at: http://www.calitateaer.ro

[14] Air Quality in Bucharest and its impact on human health. (Calitatea aerului în București. Efecte asupra sănătății) (Romanian). Available online at: http://www.ecopolis.org.ro/media/files/studiu_calitatea_aerului_bucuresti.pdf

[15] Air Quality Egg. Available online at: http://airqualityegg.com

[16] Imperial and Cambridge, "MESSAGE". Available online at: http://research.cs.ncl.ac.uk/message/

[17] Mead M., Popoola O., Stewart G., Landshoff P., Calleja M., Hayesb M., Baldovi J., McLeod M., Hodgson T., Dicks J., Lewis A., Cohen J., Baron R., Saffell J., and Jones R., "The Use of Electrochemical Sensors for Monitoring Urban Air Quality in Low-Cost, High-Density Networks," Atmospheric Environment, vol. 70, pp. 186–203, May 2013.

[18] Moltchanov S., Levy I., Etzion Y., Lerner U., Broday D.M., Fishbain B., "On the feasibility of measuring urban air pollution by wireless distributed sensor networks.", Science of The Total Environment, Volume 502, 1 January 2015, Pages 537-547.

[19] Williams D., Henshaw G., Bart M., Laing G., Wagner J., Naisbitt S., et al. "Validation of low-cost ozone measurement instruments suitable for use in an air-quality monitoring network." Meas Sci Technol 2013; 24(6):5803–14.

[20] Devarakonda S., Sevusu P., Liu H., Liu R., Iftode L., Nath B., "Real-time Air Quality Monitoring Through Mobile Sensing in Metropolitan Areas". ACM New York, NY, USA. 2013

[21] UCLA CENS: PEIR: personal environmental impact report. Available online at: http://www.viewingspace.com/peir.html

[22] Mun M, Reddy S, Shilton K, Yau N, Burke J, Estrin D, Hansen M, Howard E, West R, Boda P: PEIR, the personal environmental impact report, as a platform for participatory sensing systems research. In Proceedings of MobiSys 2009: the 7th international conference on mobile systems, applications and services: 22–25, June, 2009; Wroclaw, Poland. Edited by Zielinski K, Wolisz A, Flinn J, LaMarca A. New York, USA: ACM; 2009:55–68.

[23] CitiSense: Adaptive services for community-driven behavioural and environmental monitoring to induce change. Available online at: https://sosa.ucsd.edu/confluence/display/CitiSensePublic/CitiSense

[24] Aberer K., Sathe S., Chakraborty D., Martinoli A., Barrenetxea G., Faltings B., and Thiele L., 2010. "OpenSense: open community driven sensing of environment." ACM, New York, NY, USA, 39-42.

[25] Willett W., Aoki P., Kumar N., Subramanian S., and Woodruff A.. "Common Sense Community: Scaffolding Mobile Sensing and Analysis for Novice Users." *Proc. Pervasive 2010*, May 2010, 301-318.

[26] Romanian Law on Air Quality (Legea nr. 104 din 15.06.2011 privind calitatea aerului înconjurător. Anexa nr. 3, sect. B1 "Criterii") (Romanian). Available online at: http://www.cdep.ro/proiecte/2011/000/70/4/leg_pl074_11.pdf

[27] NO_2 sensor. Available online at: http://shop.wickeddevice.com/product/no2-sensor-mics-2710/

[28] CO sensor. Available online at: https://www.sparkfun.com/products/9403

[29] CO sensor. Available online at: http://shop.wickeddevice.com/product/co-sensor-mics-5525/

[30] Sivaraman V., Carrapetta J., Hu K., and Gallego Luxan B.. "Hazewatch: A participatory sensor system for monitoring air pollution in Sydney". In IEEE SenseApp (co-located with IEEE LCN), Sydney, Australia, Oct. 2013