The EveryAware SensorBox: a tool for community-based air quality monitoring

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Abstract: In the EU-FP7-funded EveryAware project a SensorBox is built that will be used in community-based air quality monitoring in Belgium, Italy and the UK. It is conceived as a portable multisensor array or "e-nose" using commercially available electrochemical and metal oxide gas sensors that have shown to react to traffic-related pollution.

Further tests and on-field calibration using non-linear modeling will determine the final sensor combination and the level of accuracy that can be attained in detecting and quantifying traffic pollution. Two proposed data aggregation schemes will be evaluated and the resulting level of spatial and temporal resolution will be derived.

Keywords: air quality monitoring; gas sensors; traffic pollution; mobile sensing

1. Introduction

The outdoor air we breathe contains a complex mixture of gases and particles that changes in space and time depending on the sources, the environment, meteorological circumstances and presence of other components. Many of these components are monitored with (mostly expensive) reference monitors. They give well controlled and comparable measurements, but a poor spatial coverage. Actual exposure of people to health-relevant pollutants is only poorly described by the concentrations measured in the reference monitoring stations (1).

Portable instruments are now available and used to measure personal exposure to components such as ultra fine particles (UFP) and black carbon (BC) (2,3). They are however expensive, and large scale use is therefore not obvious.

In an effort to make air quality monitoring devices available at a reasonable cost for large scale use by volunteers (community-based monitoring), several projects have developed portable devices, integrating low-cost gas sensors, GPS and mobile phones. However, quality issues, such as sensitivity, cross-interference, sensor drift, and susceptibility to temperature or humidity, are often overlooked.

A way to overcome the gas sensor limitations is the use of multivariate information from an array of different gas sensors and/or temperature and humidity sensors together with pattern recognition techniques able to detect useful patterns in the data for gas quantification and classification (also known as an electronic nose) (4). Until now, sensor arrays for air quality monitoring have only been used on fixed locations where a time series is collected to develop a regression model which is afterwards used in the same location to predict gas concentrations (e.g. (5,6)). The potential to use these low-cost gas sensor arrays in mobile applications still has to be demonstrated.

In the EU-FP7-funded EveryAware project a SensorBox will be developed that will be used in community-based air quality monitoring in case studies in Belgium, the UK and Italy. This paper describes the first step in the development of the EveryAware SensorBox.

2. The EveryAware SensorBox

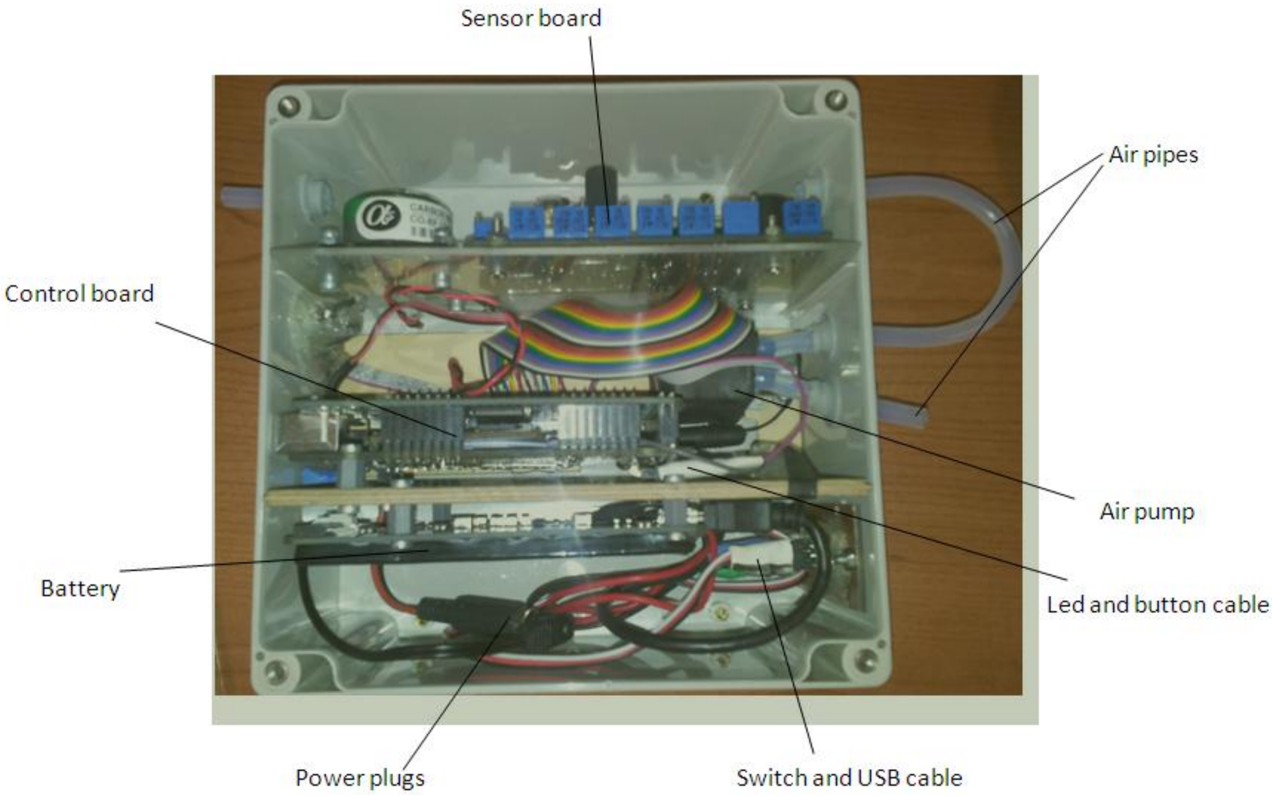
2.1.Hardware set-up

The EveryAware SensorBox is conceived as a multisensor array or an “electronic nose” (e-nose). Figure 1 shows the first version of the SensorBox with all the components needed to start measuring. The sensor board is composed of a series of sensors with their relative interface circuits. It is placed in a sensor chamber with a pump to control the air flow. The sensor chamber protects the sensors against weather influences such as exposure to wind and sun, and mitigates quick changes in the exposed air mixture.

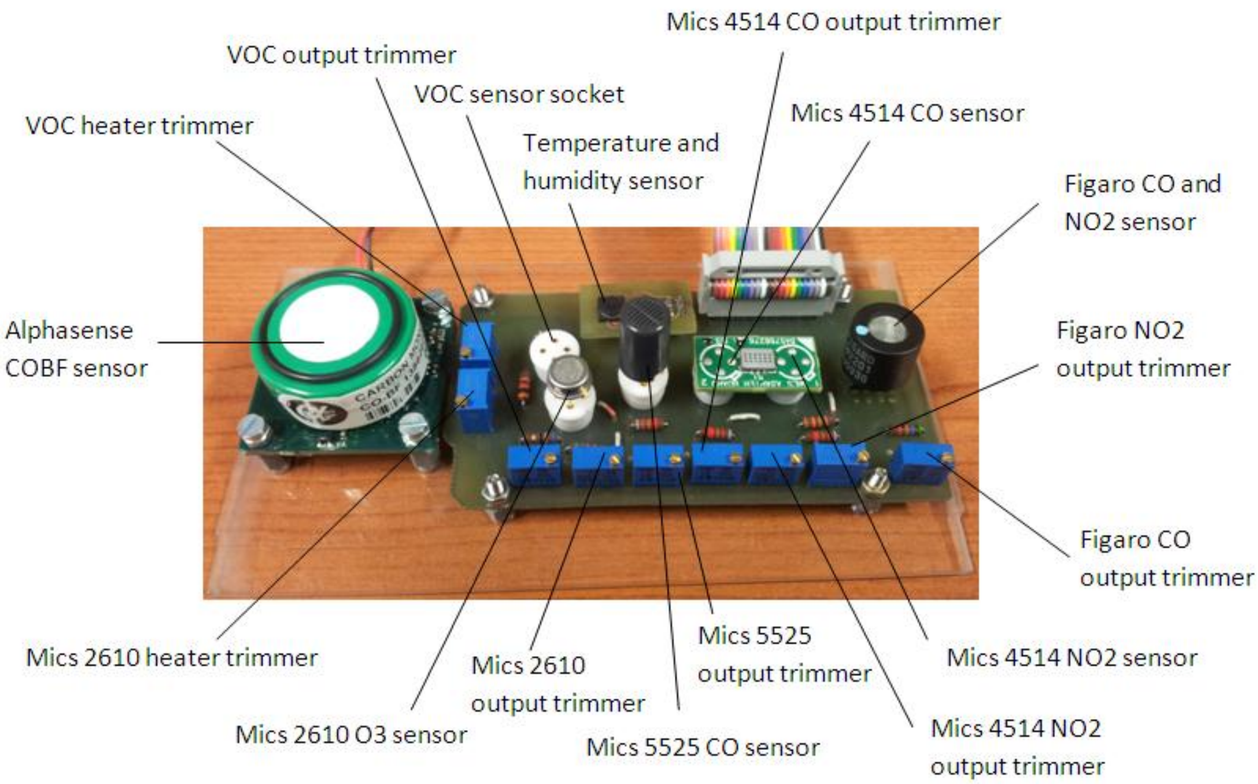
The control board acquires the data from the sensors and the GPS position at a sampling rate of 1 Hz, saves them to the SD card and eventually communicates the data to an external device through Bluetooth. This operations are controlled by a microcontroller board, Arduino Mega 2560. Stored data can be read directly from the SD card or through Bluetooth. A such it is possible to use a PC or a smartphone with Bluetooth to read and display measurements in real time or download the file with the complete data.

Further evaluation of the SensorBox will deal with the optimal air flow speed through the sensor chamber and minimal sensor stabilization time. The pump adds considerable cost to the SensorBox and its noise can cause annoyance for the user. Therefore we will investigate the possibility to replace it by a fan.

Figure 1. (**a**) The SensorBox with its main components. (**b**) Details of the sensor board (not shown: Applied Sensor AS-MLV VOC-sensor)



(**a**)



(**b**)

2.2.Choice of the sensors

Commercially available low-cost electrochemical and metal oxide gas sensors for CO or NO_2 have not been designed to measure typical ppb-concentration levels in a complex ambient air mixture. Cross-interference from other gas species and meteorological effects have a profound influence on the sensor behaviour even to an extent that they can completely mask the sensor response to the measured gas species. Behaviour of the sensor in outdoor environment cannot be predicted from laboratory calibration (7). To use the sensors in field conditions there is need for methods to correct for cross-interference and sensor drift, and to perform in field calibration.

The SensorBox contains a range of low-cost gas sensors (table 1) that have shown to react to traffic-related pollution. We carried out a set of preliminary tests, both moving and stationary outdoor, and inside a car during a ride in Brussels, to screen the sensors response to traffic related air pollution and to environmental conditions. The sensors were exposed to locations with high and low traffic intensity, and sensor responses were compared to simultaneous mobile measurements of UFP and BC, which are strongly related to traffic pollution (8). These tests showed that none of the sensors responded to traffic pollution in a consistent way. Two effects play an important role: 1) only partial response of the sensor to traffic pollution, e.g. mainly responding to CO which is not fully representative of traffic pollution; 2) effects of environmental conditions, such as changes in temperature, e.g. caused by exposure to direct sunlight, wind effects. The presence of traffic pollution was also clearly reflected by the difference in dynamics of the sensor signals.

Next to these "traffic sensors" we also added O_3, temperature and humidity sensors. They will be useful to counteract cross-interference. From our own experience and from literature we know that metal oxide sensors tend to be sensitive for the presence of ozone (9). The effect of ozone on the metal oxide sensors could also be mitigated by adding a low cost ozone scrubber.

Preliminary tests showed that the sensor chamber itself did not react with CO or NO_2.

Table 1. Low-cost sensors in the EveryAware SensorBox

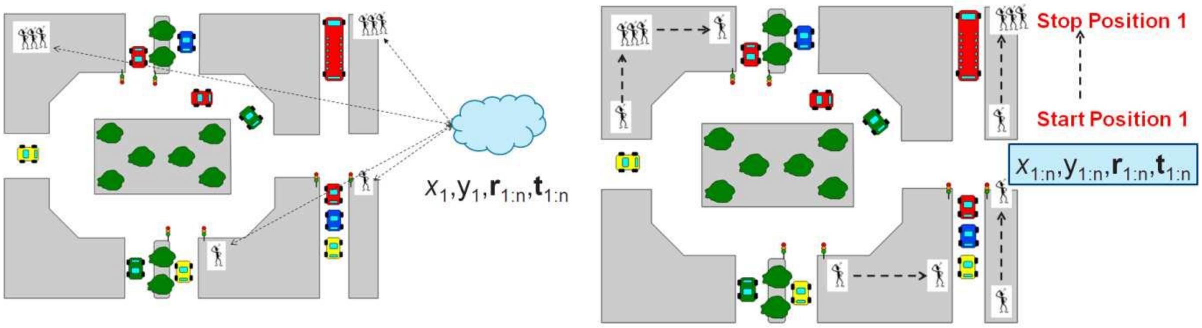
Sensor	Target gas
Alphasense CO-BF	CO
Figaro TGS 2201	Gasoline and diesel exhaust
E2V Mics 5525	CO
E2V Mics 4514	CO – NO_2
E2V Mics 2610	O_3
Applied Sensor AS-MLV	VOC
Sensirion SHT21	Temperature and Humidity

Field tests with the prototype SensorBox and subsequent data analysis will show which sensors have the highest added value in detecting and quantifying traffic pollution, which are redundant and which accuracy can be obtained. To do that on-field calibration methods will be tested using non-linear modeling, such as Gaussian Process regression. We will train the sensor array both on single gas species, and on traffic-related air pollution using portable monitors for BC and UFP, which can considered to be fair indicators of traffic pollution.

2.3.Proposed data aggregation schemes

When dealing with mobile measurements a crucial issue is the aggregation of the raw sensor signals. It is probably impossible to calibrate the sensor array for mobile near-continuous data. Therefore, two different aggregation schemes will be tested, called semi-mobile and mobile sectional approach, in order to obtain the most useful information from the SensorBox (figure 2). In the semi-mobile approach the user moves to a location of his/her interest and stays there with the sensor box for a period (order of few minutes), repeating this for other locations of interest. The second approach, the mobile sectional approach, extends the previous method from one point to an entire section of one street. The user walks with the sensor box over a certain track (order of few hundred meters) and collects data. The gathered data will be then be aggregated and used to calculate a qualitative value for the street section covered by the user.

Figure 2. Proposed data aggregation schemes. (**a**) Semi-mobile approach: The user gathers sensor information in selected points for a certain period. Data are aggregated over time. (**b**) Mobile sectional approach: The user gathers sensor information over a certain track. Data are aggregated over the entire track.



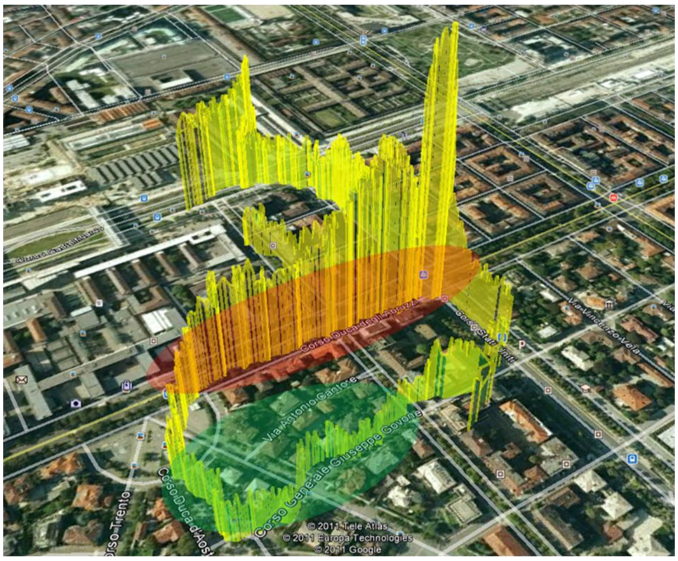
(**a**) (**b**)

2.4.First outdoor tests

Short preliminary trials were carried out walking around the Polytechnic of Turin with the SensorBox closed and hand-held. Figure 3 shows the responses of the Alphasense CO-BF sensors.

By the time of the conference we expect to be able to show the first results of field tests with the EveryAware SensorBox.

Figure 3. Results of SensorBox measurements carried out walking around the Polytechnic of Turin: graphical representation of the CO-BF sensor measurements showing a clear difference between the pedestrian area (green area) and the busy road (red area).



3. Conclusions and future work

A prototype SensorBox for use in community-based air quality monitoring has been built. The SensorBox contains a set of gas sensors that respond to traffic pollution. Further tests and on-field calibration using non-linear modeling will determine the final sensor combination and the level of accuracy that can be attained in detecting and quantifying traffic pollution. The proposed aggregation schemes will be evaluated and the resulting level of spatial and temporal resolution that can be attained will be derived. The SensorBox will be used in community-based monitoring exercises in Belgium, Italy and the UK.

Acknowledgments

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