

# Mobile Monitoring System for Control of Atmospheric Air Quality

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## Abstract

Our paper discusses a mobile monitoring system for measuring levels of the main traffic air pollutants (C<sub>6</sub>H<sub>6</sub>, NO<sub>2</sub>, NO<sub>x</sub>, CO, and CO<sub>2</sub>) in cities. The proposed monitoring device can be mounted on any vehicle (such as a car, bus, or truck) rather than being attached permanently to a dedicated van, as most systems of this kind described in the literature are. The analyzers used in this system are small portable structures containing an electronic instrument to measure, record, and transmit relevant data on pollutant levels to a website. Sample results from measurement campaigns in Gdańsk are presented.

**Keywords:** air quality, air monitoring, gaseous air pollution, traffic pollution, mobile monitoring systems

## Introduction

The desire to acquire an ever closer understanding of the state of atmospheric air and the processes taking place in it is the driving force behind the search for new methodologies and equipment that will supply tools for obtaining reliable measurements. Only these can constitute a source of accurate information for:

- determining levels of particular pollutants (xenobiotics) in atmospheric air and their evolution
- taking appropriate decisions (administrative, economic, or legal)
- supporting experimental hypotheses
- raising social awareness

Original papers on new analytical methodologies and monitoring equipment used for studying atmospheric air appear regularly in the literature [1-6]. They include systems for the remote measurement of air pollution levels based on equipment like DOAS, LIDAR, or SOLAR [7]. Also published are review papers presenting critical assessments of the state of knowledge in this field [8-10].

The first and most significant step in monitoring and mitigating air pollution is to quantify the emissions of air pollutants. Fig. 1 shows the various well-known approaches to the analysis and monitoring of air pollutants in diagrammatic form.

All monitoring systems used in the control of air quality can be classified as mobile or stationary. Most existing systems monitoring gaseous pollutants of atmospheric air and ambient aerosols, both automatic and manual, usually perform stationary measurements, i.e. they are fixed permanently to a specific location. On the basis of the data obtained from single monitoring sites, however, it is not possible to assess spatial or temporal variations in air pollutants.

'Mobile' refers to a continuous-monitoring instrument that is portable or transportable. They are usually designed to perform analytical measurements without preliminary operations. 'Portable' refers to a self-contained, battery-operated instrument, or one that is worn or carried by the person using it, or that may require the use of special vehicles for placing it in a specific area to be monitored. Transportable gas monitors can be mounted on a vehicle such as a car, plane, balloon, ship, or space shuttle, but not to a mining machine or industrial truck.

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For mobile systems the registered values of pollutants have to be correlated with information about the geographical site and current meteorological conditions (temperature and humidity).

Several contributions published during the last decade have demonstrated the advantages of mobile systems in obtaining information concerning the spatial and temporal distribution of atmospheric trace gases without the need for a dense network with stationary stations. Most of the proposed systems are based on the application of mobile laboratories [11-15] equipped with appropriate sensors. Alternatively, vehicle-mounted monitoring systems could be used.

In the development of new monitoring equipment it is particularly important to ensure that these instruments can measure air pollutant levels in real time. This is critical for assessing air pollution in large cities, where the main source of such pollution is traffic. It is important to monitor pollution along routes with the heaviest traffic, but such measurements are still rare. This is because the equipment used in fixed air quality monitoring stations (which gives accurate and reliable results) is bulky and heavy and cannot be used for measurements in motion.

The monitoring system described in this paper is made up of mobile monitoring units that are small and light enough to be placed on public transport vehicles (buses, trams) and even cars. It can be used to measure, record and transmit the concentrations of various air pollutants to a central database, together with weather conditions such as temperature, and relative humidity, and GPS coordinates.

This unit can provide support for fixed stations by taking measurements in certain places selected for additional monitoring or by measurements in motion. The suggested mobile monitoring system can determine representative concentrations of air pollution in highly populated areas, the impact of transportation sources of pollution, general background pollution levels in areas directly affected by motor vehicles, and the highest pollution levels in cities.

## Methods and Material

### Data Collection

#### *Air Monitoring Unit*

Air pollution from road traffic consists of a number of harmful substances. Some of them should be periodically measured, because of their impact on human health and state of the environment. For example, volatile organic compounds (VOCs) constitute a collective name for a very large number of different chemical species that can contribute to the formation of secondary pollutants with different efficiencies. For vehicular emissions, the list of compounds is long and variable depending on fuel, and type and condition of engine, but one of them – benzene ( $C_6H_6$ ) which is known to be a human carcinogen – is found in highest concentrations and was chosen to be measured by proposed monitoring units. Other measured gases are: nitrogen oxides ( $NO$  and  $NO_2$ ), which may harm lungs and

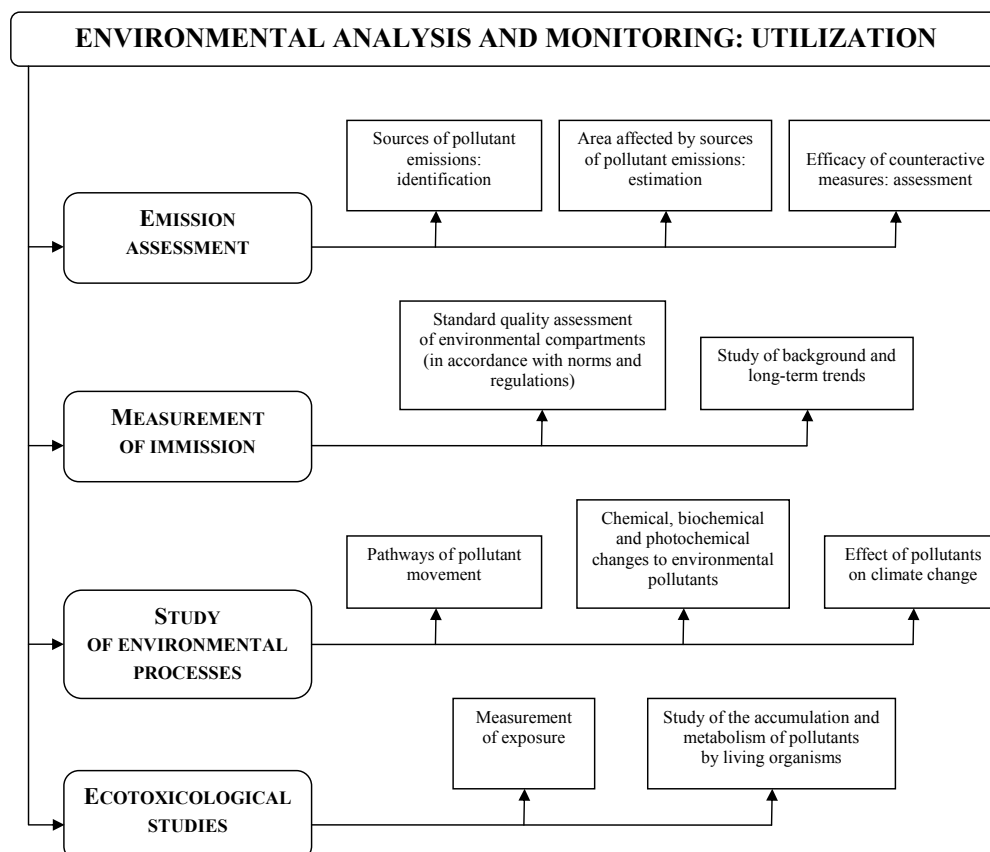


Fig. 1. The detailed goals of activities in analytics and air monitoring.

trigger asthma; ozone (O<sub>3</sub>), which can decrease lung functions and interfere with the growth of plants; carbon monoxide (CO); and carbon dioxide (CO<sub>2</sub>).

Measured concentrations of gas pollutants in air are recorded and sent via GSM/GPRS and the Internet to a central database for further processing. A block diagram of Mobile Monitoring Unit (MMU) is presented in Fig. 2. The most important component of MMU is a set of gas sensors.

These sensors react to gas concentration changes by altering the value of a component, usually resistance or electromotive force. The first version of the measurement device was equipped with a factory-made module with sensors, A/C converters, and microcontroller to convert the sensor's electric response to gas concentrations.

This module was connected to a communication unit that aggregated measurements with geographic coordinates from a GPS and sent these data to a server using a GSM/GPRS link.

Positive test results that confirmed the usefulness of the proposed device encouraged authors to build the next generation of monitoring station (Fig. 3) with additional functionalities, comparing to the original MMU unit [16]:

- more sensors for measuring concentrations of different gases in air
- mechanical construction of casing, including a special tunnel with forced constant flow of air to increase repeatability of measurements
- universal power supply unit that allows powering the device with 12 V or 24 V and contains additional battery back-up to ensure continuity of measurements
- adaptation for work in temperatures below zero degrees

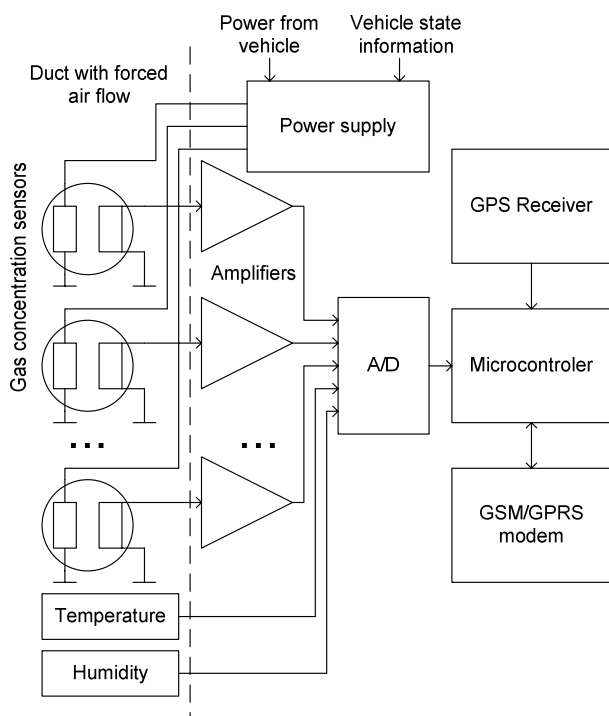


Fig. 2. Block diagram of Mobile Monitoring Unit.



Fig. 3. Mobile Monitoring Unit prototype.

Celsius by separating gas concentration sensors from electronic circuits, which requires positive temperature

Thin film sensors technology exploits the electric conduction phenomena that happens above the surface of nanostructured metal oxides (composed by micrograins of 30-50 nm diameter) between 200°C and 400°C. An electrical response from a semiconductor is proportional to particular atmospheric gas concentrations. The electrical response signal can be converted into gas concentration using a suitable calibration curve.

Such sensors are designed to detect and measure relatively high gas concentrations, at levels of mg/m<sup>3</sup>, but from an environmental point of view it is important to be able to measure concentrations at levels of µg/m<sup>3</sup>. Measuring such low levels of gas concentration requires resolving the question of instability by additional data processing after analog-to-digital conversion. The time interval between successive measurements can be configured from seconds in case of measurements in motion, to several minutes in still conditions. For a typical interval of 10 seconds, more than 8,500 data sets are collected every day, including concentrations of several different gases in air, temperature, humidity, geographic coordinates, speed of vehicle with monitoring unit, and some additional telemetry.

The proposed monitoring unit can be described as maintenance-free. The properly configured and calibrated station can operate for several months without intervention. Information about the state of operation and possible errors in the functioning of electronic components or problems with data collection is transmitted to the respective responsible person via short messages (SMS).

The results of the measurements sent to the server are verified in terms of reliability and made available to authorized users via the website as tables, graphs, and maps. Any additional data processing is made after the results are recorded in a database.

## Results and Discussion

### Equivalence of the Proposed Method of Measurement

In accordance with article 25, paragraph 2 of the “Environmental protection law” [17], the most important source of information about the state of the environment is “state environmental monitoring,” which includes a system of measurements, assessments, and forecasts of the environment and the collection, processing, and dissemination of environmental information. The objective of this monitoring is to support efforts to protect the environment by informing authorities and public about the current state of the environment. For the protection of air it is recommended to measure the concentration of different pollutants (gases) using the so-called “reference methods.” These reference methods of measurement in most cases are suitable only for stationary measurements, to create a permanent monitoring station. This paper presents a mobile monitoring system that measures the concentration of pollutants using semiconductor sensors not included in the reference methods. However, measurements made by devices not using reference methods can be taken into account, provided they prove equivalence between the proposed and reference methods.

In order to verify the equivalence of the proposed method, results obtained by the mobile monitoring units were compared with results obtained from fixed measurement stations owned by the Agency of Regional Air Quality Monitoring in Gdańsk metropolitan area.

Every monitoring unit built in laboratories of Gdańsk University of Technology was installed at the fixed monitoring stations and then during several weeks the results from the proposed monitoring units were compared with precise gas concentrations measured using reference methods. Using this comparison, the form of equations and values of coefficients to convert values of electrical signals from sensors to concentration of measured gas in air were derived. In general, these equations are non-linear; additional measurements of ppb-level concentrations make the discrepancy significant among the different sensors. This means that each copy of the mobile monitoring unit must pass a separate calibration procedure in special calibration chamber with precisely known concentrations of the particular gas. The cost of calibration is the highest in the part of total cost of the whole mobile monitoring system.

Exemplary comparison of  $\text{NO}_x$  concentration measurements obtained by the reference method and by the mobile monitoring unit using semiconductor sensors is presented in Fig. 4.

Similar results were obtained for compliance of the other gases measured: ozone, benzene, carbon monoxide, carbon dioxide, and nitrogen dioxide.

On the basis of laboratory tests and in real conditions it can be concluded that semiconductor sensors used in mobile monitoring units built in Gdańsk University of Technology ensure equivalency of results with the reference methods, recommended by the European Union for monitoring air pollution [18].

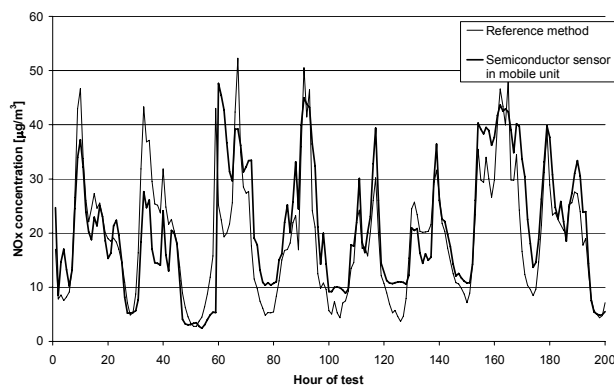


Fig. 4. Comparison of  $\text{NO}_x$  concentrations measured by proposed mobile monitoring unit and by reference method.

### Application of Monitoring Station

The main measurements carried out using the designed mobile monitoring system were related to substances emitted from vehicles that run along the Tri-City (Gdańsk-Sopot-Gdynia) communication system and the surrounding area. For example, levels of pollution were examined within the major crossroads in various states of utilization, and within selected districts of the city near main streets of Gdańsk [19].

The mobile monitoring stations were also used to determine the concentration levels of industrial pollution at distant locations from the city center and to measure traffic pollution in Warsaw.

The suitability of the designed equipment to measure ambient air pollutants was recognized during the 4th Fair of Industrial Engineering, Science and Innovation in Gdańsk (2008). The mobile monitoring system won the award of the Marshal of Pomorskie Voivodeship in the category “Environmental Protection and Ecology.”

## Conclusions

The described prototype of the mobile monitoring system, especially a self-organizing monitoring network consisting of smart measuring devices, has a universal useful form that can be used in a wide range of practical applications. Presented practical applications of the monitoring system is part of a wider security subject that currently has a high priority, both in Poland and in the world.

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