Air pollution monitoring and GIS modeling: a new use of nanotechnology based solid state gas sensors

O. Pummakarnchana*, N. Tripathi, J. Dutta

Remote Sensing and GIS FoS, School of Advanced Technologies, Asian Institute of Technology, Klongluang, 12120 Pathumthani, Thailand

Microelectronics FoS, School of Advanced Technologies, Asian Institute of Technology, Klongluang, 12120 Pathumthani, Thailand

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Abstract

Air pollution is a serious problem in thickly populated and industrialized areas in Thailand, especially in Bangkok. The air pollution in Bangkok is abundant, especially in areas where pollution sources and the human population are concentrated. Economic growth and industrialization are proceeding at a rapid pace, accompanied by increasing emissions of air polluting sources. Furthermore, though the variety and quantities of polluting sources have increased dramatically, the development of a suitable method for monitoring the pollution causing sources has not followed at the same pace. Environmental impacts of air pollutants have impact on public health, vegetation, material deterioration etc. To prevent or minimize the damage caused by atmospheric pollution, suitable monitoring systems are urgently needed that can rapidly and reliably detect and quantify polluting sources for monitoring by regulating authorities in order to prevent further deterioration of the current pollution levels. Consequently, it is important that the current real-time air quality monitoring system, controlled by the Pollution Control Department (PCD), should be adapted or extended to aid in alleviating this problem.

Nanotechnology has been applied to several industrial and domestic fields, for example, applications for gas monitoring systems, gas leak detectors in factories, fire and toxic gas detectors, ventilation control, breath alcohol detectors, and the like. Here we report an application example of studying air quality monitoring based on nanotechnology ‘solid state gas sensors’.

So as to carry out air pollution monitoring over an extensive area, a combination of ground measurements through inexpensive sensors and wireless GIS will be used for this purpose. This portable device, comprising solid state gas sensors integrated to a Personal Digital Assistant (PDA) linked through Bluetooth communication tools and Global Positioning System (GPS), will allow rapid dissemination of information on pollution levels at multiple sites simultaneously. The AQ report generated can be then published using Internet GIS to provide a real-time information service for the PCD, for increased public awareness and enhanced public participation. The local deterministic and geostatistical interpolation methods have been used for spatial prediction, and to find out the most suitable method for studying air pollution, based on observations at each monitoring site.

Keywords: Air pollution; Nanotechnology; Internet GIS; Real time monitoring system

1. Introduction

In Bangkok, where the air is thick with toxic air pollutants, increasing emissions are unavoidable due to excessively rapid economic and industrial growth. The cost of establishing and implementing ordinary monitoring systems is extremely high; use of analytical instruments are time-consuming, expensive, and can seldom be applied for real-time monitoring in the field, even though these can give a precise analysis [1]. Hence, a new generation of detectors, solid state gas sensors, offer an excellent alternative for environmental monitoring due to low cost, light weight, extremely small size and also due to the reason that they can be deployed anywhere so as to receive data that can eventually be transmitted through a Wireless GIS network system as a rapid monitoring tool to the general public. Some parts of Bangkok were chosen as a study area, covering 13 districts. The air pollutant measured was NO_x. Sampling time of each day comprised rush hours in the early morning and in the evening. In addition, other sampling
time is done when the traffic flow is normal, so as to compare the air quality between crowded and less crowded traffic conditions. The air sampling points are established at the same locations as the air quality monitoring sites of the PCD, to compare the NO\textsubscript{x} concentration values acquired from the solid state gas sensor devices and the PCD’s air quality monitoring system.

2. Aims and objectives

The aims and objectives of this approach include:

(1) To apply a suitable gas sensing device coupled to a personal digital assistant for continuous monitoring of urban air pollution and disseminate the information in real time through wireless GIS.
(2) To build up a simple monitoring system using low cost portable gas sensing systems.
(3) To assist in establishing priorities, measurements of air pollution in Bangkok and increasing public awareness and enhanced public participation.

3. Air pollution in Bangkok

From the World Bank report ‘Thailand Environment Monitor 2002 (air quality)’ [2], it can be seen that today Bangkok’s air quality ranks ahead of Beijing, Jakarta, New Delhi and Manila, but still lags behind other cities such as Hong Kong, Singapore, Taipei and Tokyo. While overall air quality has improved in the last years, it is still a problem in traffic corridors and urban centers like Bangkok. Air quality in the streets of Bangkok has become critical and the predominant cause of air pollution in downtown street is vehicle emission. Crowded traffic density and flow conditions in Bangkok city have become worse and ambient air quality has deteriorated as a result. A decade ago the health costs of exposure to lead (Pb), particulate matter (PM), and carbon monoxide (CO) in Bangkok were estimated to be equivalent to between 8 and 10% of urban annual income. These pollutants are mostly emitted by the transport sector.

During the last years the ambient levels of key pollutants-Pb, particulates, SO\textsubscript{2} and CO-in Bangkok and other urban centers have fallen dramatically. Using as an example of visibility measurements at Don Muang airport, air quality has improved since 1996, and even improvements are reported in PM\textsubscript{10} levels. Concentration levels of NO\textsubscript{x} and CO are stable and declining respectively. Also SO\textsubscript{2} levels have declined substantially as new technology has been established at the country’s power plants. Observed lead levels have fallen to almost nil, since Thailand’s complete phase-out of leaded gasoline at the end of 1995. Ozone (O\textsubscript{3}) levels are still causing concern with Maximum levels exceeding the standard [2]. According to the PCD air quality report of Bangkok recently, roadside NO\textsubscript{2}, CO and O\textsubscript{3} are significant higher than the air quality standard and general O\textsubscript{3} levels are almost higher than the standard, measured at every air quality monitoring site [3,4].

4. Air quality monitoring system

The PCD has been measuring air quality levels through the automatic monitoring system, referred as to ‘AIRVIRO SYSTEM’ [5] and reporting real time air quality levels through the Internet as air quality index (AQI) maps. Air quality monitors comprise 16 permanent stations and are set up at roadside and general sites. Unfortunately, the cost of establishing and implementing traditional monitoring systems is extremely high. In the past, the establishment of air quality monitoring systems in Thailand needed technical assistance from international agencies or governments and the investments made in these systems are extremely high, running to 250,000 US dollars. This air quality monitoring system can measure and report air quality levels in real time; nevertheless there is still a huge disadvantage that this monitoring system cannot be implemented at many sites to monitor air pollution over an extensive area because of high costs.

For non-automatic monitoring system used for measuring gases, analytic instruments such as optical spectroscopy or gas chromatography/mass spectrometry, NDIR (non-dispersive infrared), chemiluminescence, and the like can give a precise analysis; however, they are time-consuming, expensive, and are seldom used in real-time in the field. Moreover, they are difficult to transport from place to place being bulky as well. To substitute the typical analytical tools and adapt or extend the air quality monitoring system of PCD with a new generation of detectors, nanotechnology based metal oxide semiconductors such as ZnO semiconductor used in this study are a viable alternative. In fact these solid state gas sensors offer an excellent opportunity for implementation in environmental monitoring due to light weight, extremely small size, robustness, low cost and also as they can be installed anywhere to collect data covering extensive areas. The air quality data can eventually be transmitted through a Wireless GIS network system to the general public.

5. Nanotechnology

The nanotechnology realm has traditionally been defined as lying dimensions between 0.1 and 100 nm. Nanotechnology has been applied to industry for example in textile, medicine and health, computing, transportation, aeronautics and space exploration, environment, and so on. In the last decade the specific demand for gas detection and monitoring has emerged especially as the awareness of need to protect the environment has grown [6]. Gas sensors are applied in numerous fields of applications [7]. In the present case, a nanotechnology based gas sensors application for studying air
5.1. Solid state gas sensors for air pollution

Gas sensors for detecting air pollutants must be able to operate stably under deleterious conditions, including chemical and/or thermal attack. Therefore, solid state gas sensors appear to be the most appropriate in terms of their practical robustness. The sensors used for detecting air pollutants are usually produced simply by coating a sensing (metal oxide) layer on a substrate with two electrodes. Typical materials are tin oxide (SnO₂), zinc oxide (ZnO), titanium oxide (TiO₂) and tungsten oxide (WO₃) with typical operating temperatures of 200–400 °C [9]. The general mechanism for a metal oxide sensor is a change in the resistance (or conductance) of the sensor when it is exposed to pollutant gas, relative to the sensor resistance in background air. The sensor resistance is the best-known sensor output signal and is in most cases determined at constant operation temperature and by DC-measurement [9]. AC measurements have also been reported [10] but are more frequently used in impedance spectroscopy [11] at a modeling level. Fig. 1 explains how metal oxide semiconductor detects pollutant gases. The depletion zone at the surface of metal oxide sensor is due to absorption of atmospheric oxygen. When the metal oxide sensor absorbs a reducing gas (CO, H₂), depletion area at the surface will be decreased, meaning increasing conductivity. On the other hand, if a metal oxide sensor absorbs an oxidizing gas (NO₂), the depletion zone at the surface will be increased, meaning decreasing conductivity. In conclusion, a change of conductivity/resistance is related to gas concentration. In the case of a ZnO sensor, conductivity decreases that means resistance increases when the sensor absorbs NOₓ, dependent on NOₓ concentration [9].

6. Internet GIS

Internet GIS is a relationship between GIS and Internet. Users will be able to access GIS applications without purchasing GIS software by using a web browser. Detailed maps can be generated from huge databases of spatial information and distributed all over the world. The Web is a cost effective way to share or provide public access to data worldwide on the Internet.

As shown in Fig. 2, the wireless GIS Data Logging System being developed in this study is composed of two parts, i.e. hardware and software. On the hardware side, a Mandrake 9.1 Server provides the back-end support. A user has in hand a PDA operated on Pocket PC. So as to be complete, a Global Position Receiver (GPS) and Digital camera can be also integrated through proper extensions. On the software side, a Minnesota Map server 4.4.0 ensures Web Map Service (WMS), which is an Open Source Common Gateway Interface (CGI) based development environment for building spatially enabled Internet applications. The server setup is made up of PostgreSQL, PostGIS and PHP, configured with each other to execute the client’s request and manage the database. The client setup is composed of interfaces, developed using JavaScript and Hyper Text Markup Language (HTML) [12].

For wireless Data Updating System, it is composed of three tiers, including Front-End Tier, Middle-Tier and Back-End Tier. On the Front-Tier is the client, making a request, Minnesota Map Server in the Middle Tier passes the CGI-request over to the Back-End Tier where PHP and PostgreSQL with PostGIS read the data and execute the request.

7. NOₓ observation using the ZnO sensor

The data used for this study are composed of measured NOₓ concentration from 12 stationary air quality monitoring sites as shown in Fig. 3. A limited number of observation sites were taken to test the method at locations which are critical for automobile pollution. The data were collected every hour from 7:00 h until 19:00 h, which were fed to the GIS for further processing. It is supposed that more air sampling points are needed for more accurate interpolation techniques [13], or interpolation by creating a buffer at each
point is supposed to be more suitable method for this study as shown in Fig. 3.

8. Integrating GIS with nanosensors

As shown in Fig. 4, the solid-state gas sensor gives out electric signals, related to NO$_x$ concentration. An A/D circuit converter converts the NO$_x$ concentration values from an analog to digital signal. NO$_x$ concentration levels, acquired from monitoring sites, GIS base maps and attributes were input into PDA linked with GPS. The results were utilized for air quality level modeling of the study area. The model developed were used for acquiring and monitoring real time air quality levels and also updating information through wireless GIS using WMS. The information on the resulting air quality levels can operate as a monitoring system and be displayed in the form of GIS database. The air quality levels were categorized into five classes, overlaid with Bangkok GIS base maps. The five classes of air quality level reported include hazardous, very unhealthy, unhealthy, moderate and good. Hence, Internet users can browse and query air quality interpolated maps, relating to geographic information, including districts, roads, urban settlement, historical air quality level, population as shown in Fig. 5. The Internet based GIS is useful real time interaction on air quality levels and increases public awareness and participation.

9. Conclusion and discussion

Current air quality of Bangkok is better than a decade ago. However, Bangkok still has been facing serious air pollution problems. As seen in central Bangkok, black and white smoke from truck and public bus exhaust still occurs. This is attributed to the rapid economic and industrial
growth, combined with a lack of strict implementation of air quality and requires the PCD to adapt or extend the current PCD’s air quality monitoring systems and also facilitate the problem of analyzing and monitoring air pollution in Bangkok area.

The traditional air quality monitoring system, controlled by the PCD, is extremely expensive. Analytical measuring equipment is costly and time consuming, and can seldom be used for air quality reporting in real time. The PCD has been forecasting and reporting real time air quality levels through the Internet in the form of maps. However, the air quality index of each monitoring site is just shown by rather coarse levels; good, moderate, unhealthy, very unhealthy and hazardous. The air quality report should be more in detail, including information such as air quality interpolated maps, relating to other information for better understanding the air quality level. For these reasons, this work is aimed to build up an easy monitoring system using low cost portable gas sensing systems ‘solid state gas sensors’ so as to carry out air pollution monitoring over an extensive area and to be able to report real time air quality data through Wireless Internet GIS. Later all this modeling can be referred to as an air pollution monitoring system, which will be able to support the PCD to adapt or extend the current PCD’s air quality monitoring systems, to facilitate the problem of analyzing and monitoring air pollution, and also to assist in establishing priorities and measurements of air pollution in the Bangkok area.

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Ms Pummakarnchana is currently PhD student on Remote Sensing and GIS at the Asian Institute of Technology in Bangkok. She received her MSc in Environmental Technology from Mahidol University, Bangkok in 2002 based on her applied research on the air dispersion model ISCST with GIS application. She finished her BSc in Environmental Science Cum Laude at Silpakorn University Bangkok in 1999. Her research focuses on environmental and air pollution monitoring and management, GIS and remote sensing application. She received several scholarships and recently the Best Speaker Award from the Asian Association on Remote Sensing during the 25th Asian Conference on Remote Sensing (ACRS 2004), Chiangmai, Thailand.