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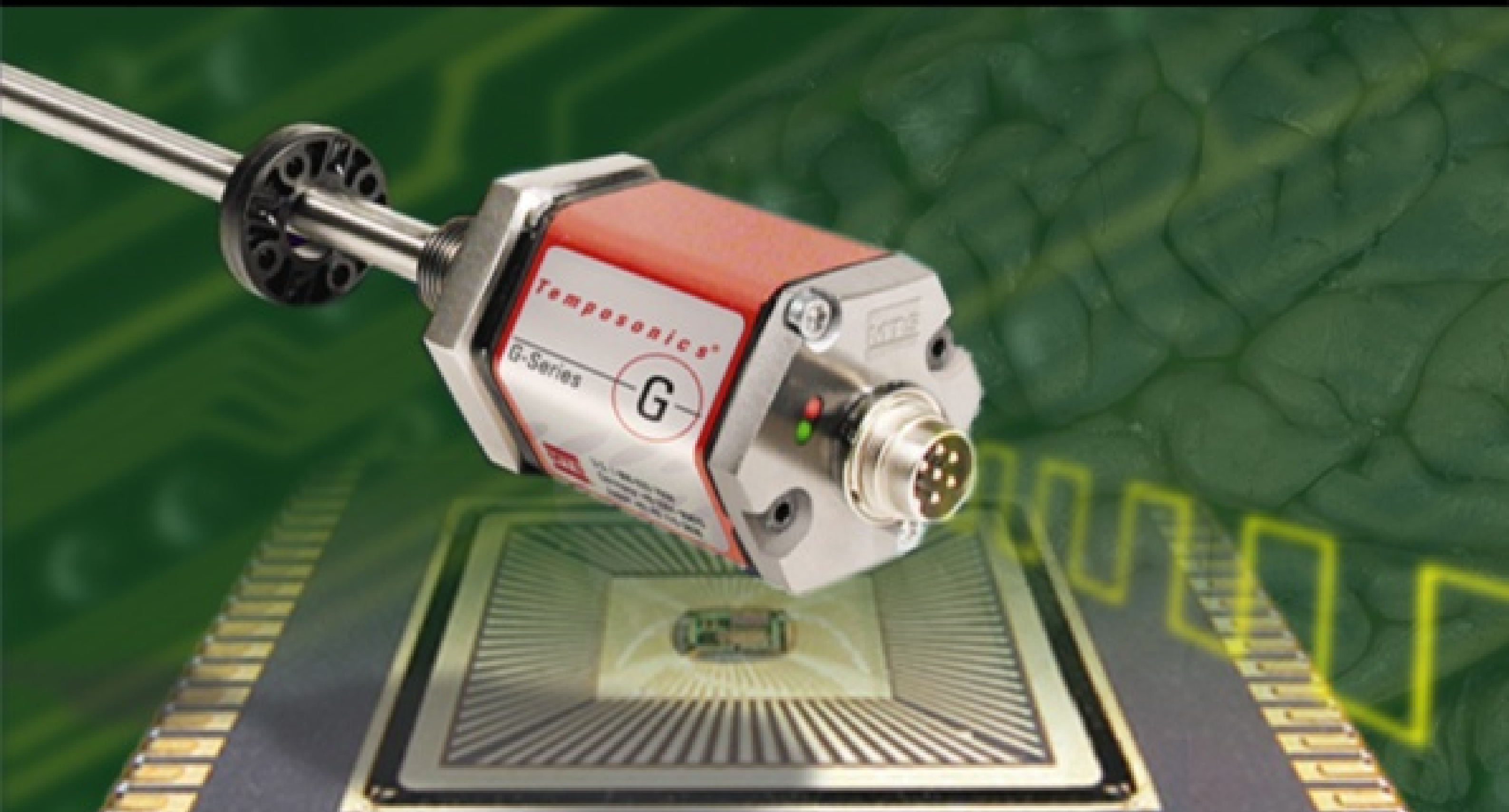

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Real-Time Air Pollution Monitoring in Urban Environment Using *In-Situ* Measurements Using WO_3 Gas Sensors and Satellite Imagery Through Internet GIS

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Abstract: Air pollution is a serious problem in densely populated and industrialized areas in some Asian countries. The area investigated for this study is Bangkok, Thailand. The air pollution in central Bangkok is significant in areas with high population density. To monitor air pollution over a large area, this research aims at developing a cost-effective and real-time air pollution monitoring system that utilizes numerical modeling in conjunction with inexpensive, state-of-the-art gas sensors, remote sensing methodologies, and Internet GIS. Conventional pollution detectors, installed by the Bangkok Pollution Control Department, as well as WO_3 sensors are employed for *in-situ* pollution measurements. The data obtained from the satellites sensors and measurements conducted on ground are used for numerical modeling by "Multiple Regressions" to investigate air pollutants distribution. The analysis and correlation of the air pollutants data are transferred to a Personal Digital Assistant linked via Bluetooth communication tools and Global Positioning System for rapid and simultaneous dissemination of information on pollution levels at multiple sites. *Copyright © 2007 IFSA.*

Keywords: Internet GIS, Real time air pollution monitoring system, Remote sensing, Tungsten oxide semiconductor sensor

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1. Introduction

In the present technology dominated modern society, the environment has undergone a vast and complicated transformation due to increased urbanization and industrialization, particularly in large cities. To meet our ever-rising demand of energy for a better quality of life creates a conflict between generation and consumption of energy with continued degradation of the environment. Air pollution is an extremely serious problem in densely populated and industrialized areas in some Asian countries. The area under investigation for this study is Bangkok, Thailand. The air pollution in central Bangkok is significantly large, particularly in areas with large sources of pollution and a high population density. The pollutants that contaminate urban environment are nitrous oxide (NO_x), fine suspended PM, sulphur dioxide (SO_2), and ozone (O_3) causing the most widespread and acute health related risks. Recent studies on the effects of chronic exposure to air pollution have singled out PM suspended in smog (NO_X) and volatile organic compounds (VOCs) as the pollutant that are the most responsible for life-shortening respiratory and associated health disorders. Some of the primary pollutants causing serious air pollution problem in Bangkok are Oxides of Nitrogen (NO_2, NO_x), O_3, VOCs and Particulate Matter ($PM_{10,\ 2.5}$), as reported by the PCD, Thailand. Furthermore the Global NO_2 column (molecule cm^{-2}), as detected by the satellite such as SCIMACHY, clearly shows that NO_2 columns are increasing at a rapid pace in and around Bangkok area since 2003 [1]. Many pollutants, such as Carbon monoxide (CO), SO_2, suspended particles in VOCs, etc., also exist in the general Bangkok urban environment, however, the present investigation focuses on monitoring and analyzing NO_x, O_3 and PMs as the representative pollutants, employing cost-effective metal-oxide gas sensors. These gas sensors can readily be deployed for field testing and real-time monitoring as compared to the conventional air pollution monitoring systems which are time-consuming and expensive [2].

The investigation presented here employs data obtained by WO_3 semiconductor-type gas sensors in conjunction with satellite imagery as a cost-effective and efficient alternative for monitoring air quality. This approach is fairly inexpensive, portable due to its compact size, and offers real time-data monitoring capability. Furthermore, the air quality monitoring unit, as described in this investigation, can be deployed anywhere and transmit data that can eventually be routed via an Internet GIS network system as a rapid monitoring tool to the general public and policymakers. The data from the gas sensors monitoring air pollutants is uploaded in real time via PDA to the air quality monitoring server as concentration values. Users can simply browse and view the air quality data in graphical format in real-time. Sampling time of each day comprises, in general of rush hours - typically in the early morning and in the evening. In addition, other sampling times are also carried out when the traffic flow is normal, so as to compare the air quality levels between dense and less traffic conditions. Thus, the objectives of this investigation are twofold, viz.; (a): to apply a network of semiconductor type gas sensor coupled to PDA type devices for air pollution monitoring in urban area and disseminate the information in real-time via PDA and wireless GIS, and (b): to assist policymakers in establishing priorities, measurements of air pollution in Bangkok and increasing public awareness and enhanced public participation. The data obtained from the satellites sensors and measurements conducted on ground using the gas sensors are also used for numerical modeling for correlation of the air pollutants distribution. The ultimate objective of this investigation is to deploy gas sensors in metropolitan cities worldwide to be able to monitor pollution levels in real time. Availability of pollution levels data and its correlation with respiratory ailments will be a great tools for policymakers in developing an Alert and Response System (ARS©). Subsequent implementation and/or modification in policies to reduce pollution will help millions of people in enhancing their quality of life.

2. Study Area

Bangkok was chosen as a model study area which is home to approximately 8 millions people. Approximately 20 % of the total population of Thailand is concentrated in less than 6 % of its territory.

In Bangkok, most of the population (slightly over 8 million habitants) lives in the Bangkok metropolitan area and the remaining people live in the vicinity of Bangkok, defined as the neighboring provinces of Pathum Thani, Nonthaburi, Samut Prakan, and Samut Sakhorn. This overall population is distributed very unevenly over the central plain as human density culminates in Bangkok and its vicinity to 5111 habitants/km^2 but has an average of approx. 117 habitants/km^2 in the remaining rural areas. The study area covers 1569 kilometer square consisting 50 districts as shown in Fig. 1, and the inset is displayed using Quickbird satellite, zoomed at an altitude of 10 Km, as obtained from Google Earth website, clearly showing congested areas. Real-time monitoring of pollution is thus critical for Bangkok, as there are many reported cases of respiratory related illnesses due to severe emission of pollution – thus providing impetus of this investigation. It is the opinion of the authors that the unit reported here can readily be deployed in large metropolitan cities worldwide for similar investigations.

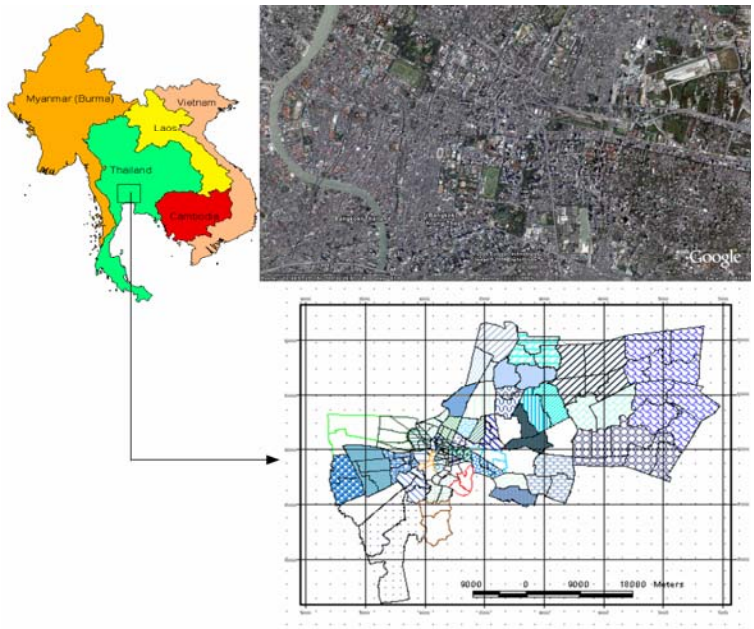

Fig. 1. The study area of Bangkok.

2.1. Experimental Investigations

Recent development of thin semiconductor films employing nanostructured materials, Nerst-type potentiometeric devices based on solid-electrolyte membrane, and Nickel oxide/Zinc oxide (NiO/ZnO) capacitor type gas sensors and detectors offer excellent alternatives for environmental monitoring. The devices are low cost, light weight, and relatively small in size. Several different kinds of thin-film sensors are commercially available as well, for detection and monitoring of NO_x gas. These sensors and sensing materials include lead phthalocyanine (PbPc), thin film (Palladium Platinum Gold) Pd-PtAu-WO_3, Thick film (Titanium Oxide) TiO_2-WO_3, and WO_3 semiconductor type Schottky structures [3]. For this investigation, low cost, metal-oxide (WO_3) semiconductor junction with Schottky structure type sensors were used. The WO_3 based sensors were purchased from the Synkera Technologies and packaged in a commercial electronic package (P/N 7000006) [4]. Platinum was used as an electrode to measure conductivity changes of the sensor operating at a working temperature of about 250 ºC [5]. In terms of its principle of operation, the resistance change is primarily caused by loss or gain of surface electrons as a result of adsorbed oxygen reacting with the target gas. The WO_3 semiconductor layer used in this investigation is an n-type oxide which increases in resistance in the presence of oxidizing gases such as NO_2 or O_3 and decreases in resistance in presence of reducing gases, such as CO or methane (CH_4). A possible interaction mechanism between NO_2 and WO_3 may be through superficial W^{5+} may be described as:

$$NO_2 + W^{5+} \leftrightarrow (W^{6+} -NO_2^-) \quad (1)$$

Hence the response of metal oxide based gas sensor response to NO_2 is caused by adsorbed species which capture electrons and hence make sensor resistance (thus voltage) to increase [6].

2.2. WO_3 Sensor Calibration and Gas Sensitivity

The calibration experiments were conducted at Petro-Instruments Corp. (PICO) Ltd in Chatuchak, Bangkok. The concentrations of NO_2 gas in 0-7.34 ppm range were measured using varying gas mixtures of O_3 and NO_x by employing a 'Programmable Multi-gas Calibrator' model 5008. The gas calibrator is linked simultaneously to NO_x gas analyzer using a "Dual Chamber Chemiluminesce" gas monitor, from Environment S.A., to accurately acquire NO_2 concentrations produced by the multi-gas calibrator. The ratio used for mixing gases was NO_x:O_3 (1:1) by gas volume. Besides flow meter "DC-lite" - which uses patented Dry-Cal near-frictionless piston technology and photo-optic sensors were used to obtain volumetric flow readings quickly and accurately. The air and gas flow rate were adjusted at 70 ml/min. Power source was provided by a 9V and 1.2 mAH adapter. The sensor was inserted into a plastic chamber of 10 ml volume under continuous flow of testing gas mixtures at a constant flow rate. Before measuring NO_2 gas each time, the sensor was stabilized for a minimum of 16 hrs at room temperature**.** At each calibration of the sensor response, WO_3 gas sensor was exposed to NO_2 gas for 5 min with absence of air in between each sensor response test for 2 min. A schematic diagram of the calibration system is illustrated in Fig. 2.

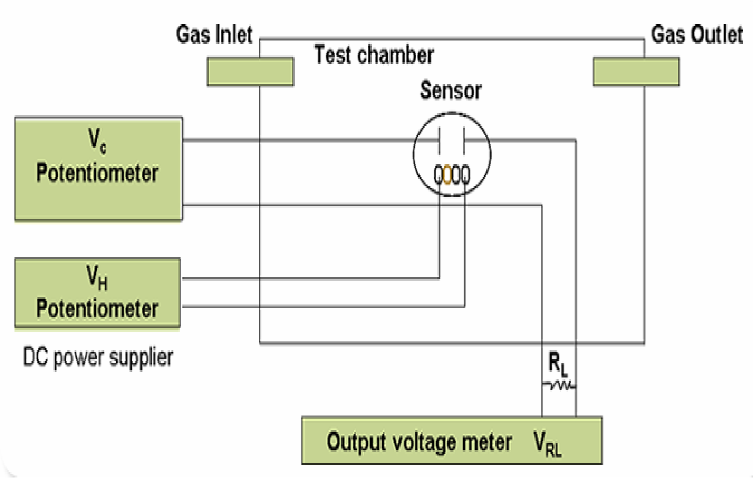

Fig. 2. Schematic of the measurement system. Legends: V_c: circuit voltage; V_h: heater voltage; R_L: load resistance; V_{RL}: output voltage.

2.3. Real Time Air Quality Monitoring In Urban Environment Using Internet GIS and Satellite Imagery

Conceptual framework for real time air quality monitoring based WO_3 gas sensors and satellite imagery through Internet GIS [7] is shown in Fig. 3. The composition of input consists of data obtained from, (a): WO_3 semiconducting gas sensors, (b): *in-situ* pollution measurements from the PCD, and (c): satellite imagery. The satellite imagery consists of data from the MODIS (Near Infrared Band) [8], Landsat ETM^+ Data (10.4-12.5 μm), and SCIMACHY (Thermal Infrared band) so as to detect aerosols, PM, and NO_2 respectively. From the literature review, it seems that most of the investigations on air quality based satellite data have been carried out by using Landsat TM7 and MODIS data. In this work, data obtained from SCIMACHY is incorporated due to its high spectral resolution in the range from 0.3-0.6 μm for thermal infrared band. All of satellite imagery was analyzed using the second order polynomial coordinates transformation in order to relate to ground control points in the area under study to match to their corresponding row and column positions. A geometric correction method "nearest neighbor" was applied to the obtained satellite imagery to ensure that the digital numbers (DN) of each image stay the same. The DN values for the near infrared and thermal band of the equivalent aerosols, PM and NO_2 measurement locations, respectively, were extracted and correlated with *in-situ* measurements using multiple regression means. For the data input retrieved from WO_3 semiconducting sensors, the sensors provided electric signals, based on the NO_2 concentrations, which were directly converted into digital format employing analog to digital (A/D) converter. Afterwards, all of input data mentioned above including WO_3 sensors, *in-situ* measurements and satellite imagery were collected and input to the GIS for further processing, to prepare a comprehensive air quality levels database using PostGreSQL (Extension of PostGIS). The data of pollutant concentrations, GIS base maps, satellite imagery and attributes were uploaded to the mapserver as a map file. The results are employed for air quality modeling of the central Bangkok area, which can be applied for disseminating and monitoring real time air quality levels as well as updating information through the Internet GIS using Web Map Service.

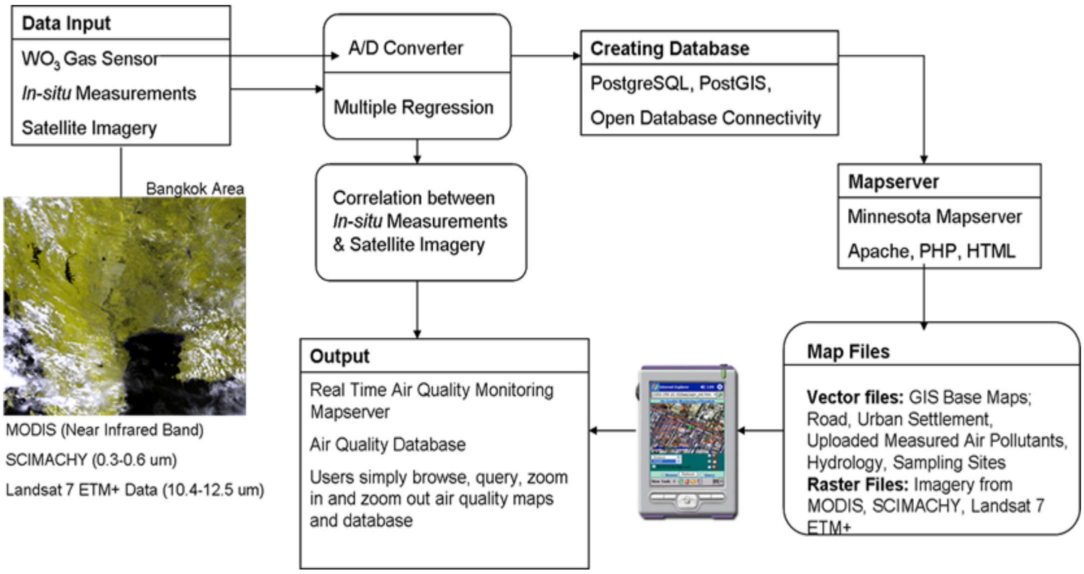

Fig. 3. Conceptual framework for real time air quality monitoring based WO_3 Gas Sensors and Satellite Imagery through Internet GIS.

3. Results and Discussion

3.1. Typical Responses of WO_3 Semiconducting Sensor to NO_2 Gas

Fig. 4 shows characteristics of sensor responses with different gas concentrations. The gas sensors were tested for sensitivity, selectivity, stability, and reproducibility. A representative data indicates that the sensors typically exhibit a linear response, as illustrated in Fig. 4a The data supports the investigation of Wang et al., [9], in which the sensitivity of WO_3 film calcinated at 500 °C display linear response as a function of exposed concentration of NO_2**.** For a typical sensor, when observed on a curve of voltage output versus concentration plot, the characteristic of sensor response displays a linear correlation between NO_2 gas concentration and voltage output measured from the sensor, with a regression coefficient of 0.94, indicating correlation within experimental margin and the data show reproducible responses across this range of exposed concentrations. The response and recovery time of the sensor is dependent on the NO_x concentrations. The circuitry in the sensor refreshes itself periodically for reproducible results. In addition, different gases were exposed to the sensors in order to investigate the selectivity of sensor response [10]. The sensor was exposed to NO_x gas in 0-7.54 ppm range to investigate the characteristics of sensor response to varying concentrations as shown in Fig. 4b. To investigate further the stability characteristics of sensor response to NO_x, the sensor was exposed to pure NO_x gas of 10 ppm for 5 minutes displaying fairly uniform response [10].

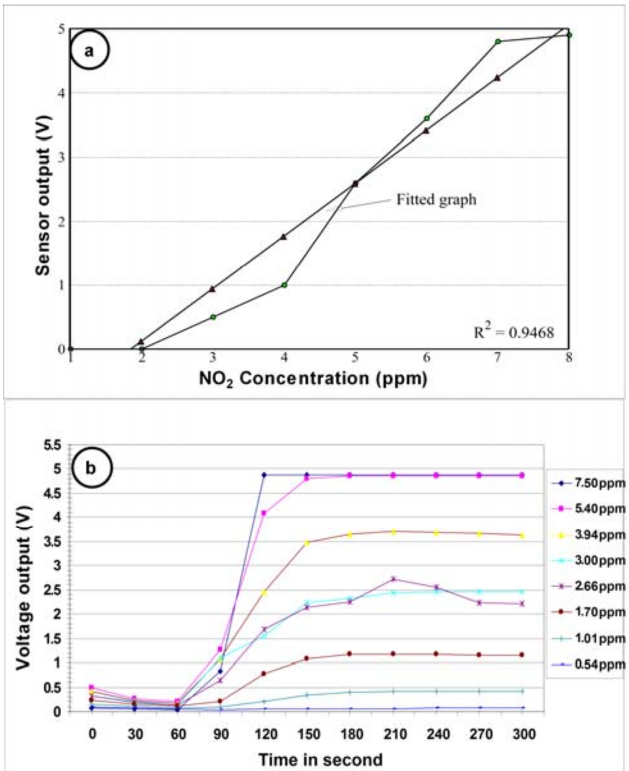

Fig. 4. Typical responses of WO_3 semiconducting sensor to NO_2 in 0.54-7.50 ppm range and in linearity to different concentrations of NO_2 challenge.

3.2. Real Time Air Quality Monitoring in Urban Environment Using GIS Modeling and Satellite Imagery

The air quality dissemination and monitoring model developed is applied in central Bangkok environment so as to retrieve and monitor real time air quality levels of aerosols, PM_{10}, and NO_2 and also to continuously update information through wireless GIS and map-server service to be displayed in the form of GIS database. The air quality levels were overlaid with Bangkok base maps and satellite imagery. The three classes of air quality levels reported include low, moderate, and high correlated to the National Ambient Air Quality Standard of the PCD. Internet users, hence, can browse and query air quality based maps, related to geographic information, including districts, urban settlement (education, offices, villages, temple, and the like), roads, railways, hydrology, and with satellite imagery as a background. The server is programmed such that the air quality events that were monitored for past 48 hours can be queried at a given time. The fundamental functions are developed for both PDA and PC users including the buttons of browse, refresh map, query, zoom in, pan, and zoom out to retrieve map layers. Fig. 5 shows a typical screen view and pollution distribution for a site under investigation.

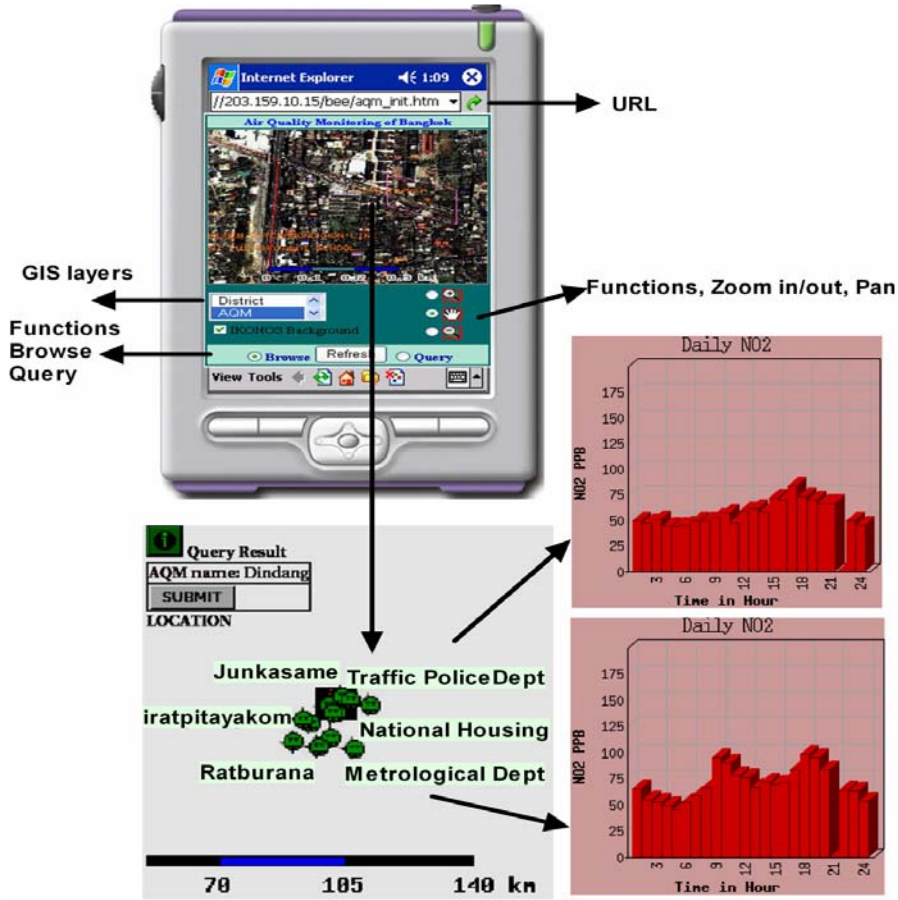

Fig. 5. Real time air quality monitoring in urban environment using GIS modeling and satellite imagery: the current low NO_2 concentration levels covering 70-100 meter around the Dindang station.

As an extension to this project, an optical model to calculate aerosols optical depth is in progress. Studies are carried out to estimate absorption and scattering properties as well as backscattering probability of the suspended matter. Such events, in conjunction with spatial distribution of temperature, air currents, and VOC and other pollutants concentration will be able to validate the satellite based observation. Furthermore, hyperspectral measurements in conjunction with the proposed optical model will provide a theoretical basis and practical basis for space based measurements and its correlation with observation on the ground, viz. quantifying as to how much aerosol is in the air by investigating the transmission of the sunlight. Additionally, users will be able to query the current and daily air quality level in graphical formats using OWTChart open source software. Remote sensing methodologies are currently used to identify urban air pollution concentrations of NO_2, dust distribution, and aerosols, which are modeled respectively using Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIMACHY) (0.3-0.6 μm), Landsat 7 ETM^+ data and Moderate Resolution Imaging Spectroradiometer (MODIS).

4. Conclusions

It was established, using this investigation that cost-effective WO_3 semiconducting gas sensors can provide good performance characteristics, such as high sensitivity (<0.5-7.50 ppm), reproducibility, insensitivity to moisture and reliable operation at relatively high temperatures. The sensors in conjunction with Internet GIS are a viable tool to monitor pollution in urban environments. Remote sensing techniques using satellite imagery obtained from SCIMACHY, MODIS and Landsat 7 ETM+ Data can be applied to investigate the real time urban air quality levels and its correlation with ground based measurements. The Internet based GIS is a user friendly, real-time, interactive tools to provide data on air quality levels and will help increases public awareness and participation.

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