A Mobile GPRS-Sensors Array for Air Pollution Monitoring

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***Abstract*—An online GPRS-Sensors Array for air pollution monitoring has been designed, implemented, and tested. The proposed system consists of a Mobile Data-Acquisition Unit (Mobile-DAQ) and a fixed Internet-Enabled Pollution Monitoring Server (Pollution-Server). The Mobile-DAQ unit integrates a single-chip microcontroller, air pollution sensors array, a General Packet Radio Service Modem (GPRS-Modem), and a Global Positioning System Module (GPS-Module). The Pollution-Server is a high-end personal computer application server with Internet connectivity. The Mobile-DAQ unit gathers air pollutants levels (CO, NO2, and SO2), and packs them in a frame with the GPS physical location, time, and date. The frame is subsequently uploaded to the GPRS-Modem and transmitted to the Pollution-Server via the public mobile network. A database server is attached to the Pollution-Server for storing the pollutants level for further usage by various clients such as environment protection agencies, vehicles registration authorities, and tourist and insurance companies. The Pollution-Server is interfaced to Google Maps to display real-time pollutants levels and locations in large metropolitan areas. The system was successfully tested in the city of Sharjah, UAE. The system reports real-time pollutants level and their location on a 24-h/7-day basis.**

***Index Terms*—Air pollution, general positioning systems (GPSs), microcontrollers embedded systems, wireless mobile networks.**

I. Introduction

MANY air pollution systems in urban and rural areas that utilize smart sensor networks and wireless systems were reported in recent literature. An environmental air pollution monitoring system that measures CO, NO2, and SO2 was reported [1]. The system is based on a smart sensor microconverter equipped with a network capable application processor that downloads the pollutants level to a personal computer for further processing. A wearable and wireless sensor system for real-time monitoring of toxic environmental volatile organic compounds was developed in [2]. An air pollution geo-sensor network consisting of 24 sensors and 10 routers was installed to monitor several air pollutants in [3]. The system provides alarm message depending on the detected pollution types in the field. A high-resolution surveillance Web-camera was used to monitor air quality via the Internet [4]. The Web-camera can be connected to network via a wired modem or wireless WiFi connection. A wireless mesh network based on embedded microprocessors consisting of multiple sensors and multihop wireless communication is designed to cover a geographic area in [5]. The system monitors and transmits parameters atmospheric environment to a command center. Another wireless sensor network system was developed to monitor indoor air quality in [6]. The indoor environmental parameters were monitored and transferred to a client personal computer or personal digital assistant (PDA) using an RF transmitter. An outdoor air pollution monitoring system using ZigBee networks for ubiquitous-cities was reported in [7]. The system integrates a wireless sensor board which employs dust, CO2, temperature, and humidity sensors. The system's monitoring range is 270 m [7]. An abstract model of a system based on long-range wireless communication was proposed in [8].

Most of the above air pollution and quality monitoring systems are based on sensors that report the pollutants levels to a server via wired modem, router, or short-range wireless access points. In this paper, we propose a system that integrates a single-chip microcontroller, several air pollution sensors (CO, NO2, SO2), GPRS-Modem, and a general positioning systems (GPSs) module. The integrated unit is a mobile and a wireless data acquisition unit that utilizes the wireless mobile public networks. The unit can be placed on the top of any moving device such as a public transportation vehicle. While the vehicle is on the move, the microcontroller generates a frame consisting of the acquired air pollutant level from the sensors array and the physical location that is reported from the attached GPS module. The pollutants frame is then uploaded to the General Packet Radio Service Modem (GPRS-Modem) and transmitted to the Pollution-Server via the public mobile network. A database server is attached to the Pollution-Server for storing the pollutants level for further usage by interested clients such as environment production agencies, vehicles regeneration authorities, tourist and insurance companies. The Polution-Server is interfaced to Google maps to display real-time pollutants levels and their locations in large metropolitan area such as Sharjah City, UAE.

The rest of the paper is organized as follows. Section II specifies the system functional and nonfunctional requirements. Section III describes system hardware. The software architecture is described in Section IV. The results, implementation and testing are reported and discussed in Section V. Finally, the conclusion is presented in Section VI.

II. System Requirements

A system can be characterized according to its functional and nonfunctional requirements. Functional requirements describe

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the primary functionality of a system while nonfunctional requirements describe attributes like reliability and security, etc. The system's functional requirements are as follows.

- System must support accurate and continuous real-time data collection.
- System needs to store the data and provide access to a location map interface.
- System needs to support mobility.
- System must use minimum power.
- System must be accessible from the Internet 24/7.
- System must be compact.
- System must mostly use off-the-shelf devices, components, and standards.
- System must support two-way communication between the client and the server.
- System must be field-configurable.
- System should be easy to deploy.

Nonfunctional requirements for the system dictate that the system is reliable, portable, accurate, maintainable, secure, accessible, and usable. In addition, the system must support performance standards for an adequate response time and storage space for data.

III. Hardware Architecture

To satisfy the system's functional and nonfunctional requirements, two major building blocks are needed, namely: a Mobile Data-Acquisition Unit (Mobile-DAQ) and a fixed Internet-Enabled Pollution monitoring Server (Pollution-Server).

The Mobile-DAQ unit is designed by integrating the following hardware modules shown in Fig. 1. As the figure shows, the Mobile-DAQ consists of a 16-bit single-chip microcontroller integrated with a sensor array using analog ports. The Mobile-DAQ is also connected to a GPS module and a GPRS-Modem using the RS-232 interface. Each of these components is described in the following.

A. 16-Bit Single-Chip Microcontroller

The microcontroller is a single-chip device that has rich built-in resources for digital input/output ports, 16 channels, 8/10 bits analog-to-digital converter, 8 input/output interrupt-driven timers, 12 Kbytes of RAM, 4 Kbytes of EEPROM, 256 Kbytes of FEEPROM, two RS-232 serial communication ports, 4 Control Area Networks ports, I^2C and SPI communication ports [9]. These resources are more than enough for the proposed application.

B. Sensors Array

The sensor array consists of three air pollutions sensors including Carbon Monoxide (CO), Nitrogen Dioxide (NO2), and Sulfur Dioxide (SO2) [10].

As Table I shows, the resolution of these sensors is sufficient for pollution monitoring. Each of the above sensors has a linear current output in the range of 4 mA–20 mA. The 4 mA output corresponds to zero-level gas and the 20 mA corresponds to the maximum gas level. A simple *signal conditioning circuit* was designed to convert the 4 mA–20 mA range into 0–5 V to be compatible with the voltage range of the built-in analog-to-digital converter in the 16-bit single chip microcontroller described earlier.

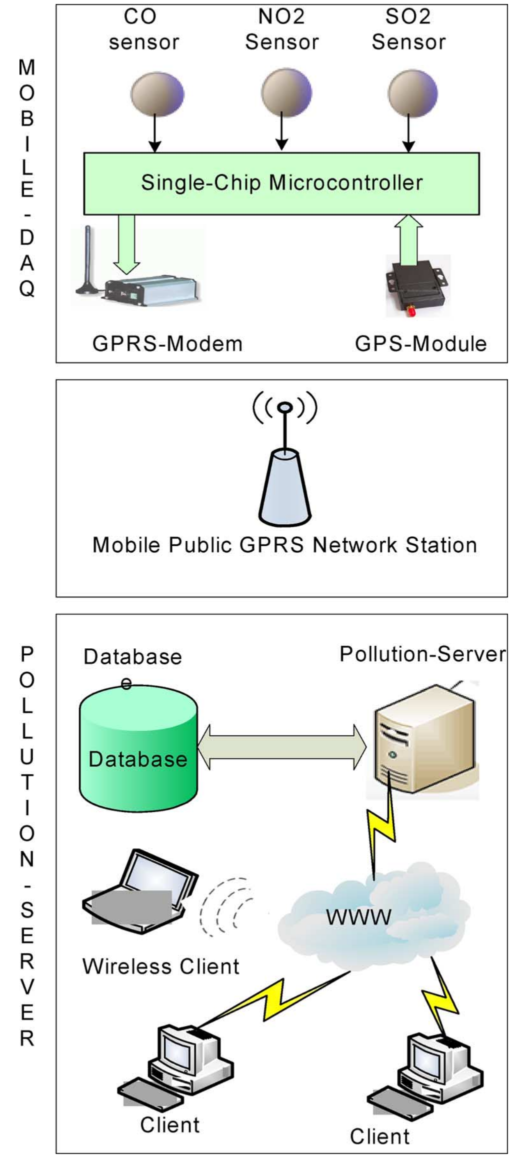

Fig. 1. System hardware basic building blocks.

TABLE I
SENSOR ARRAY SPECIFICATION [10]

Sensor	CO	NO2	SO2
Resolution (ppm)	<1.5	<0.02	<0.1
Resp. time (t90) (s)	<25	<60	<25
Op. range (ppm)	0-1000	0-20	0-20
Operating life (yrs)	> 2	> 2	>2
Diameter (mm)	20	20	20

C. GPS Module

The GPS module provides the physical coordinate location of the mobile-DAQ, time and date in National Marine Electronics Association (NMEA) format [11]. NEMA format includes the complete position, velocity, and time computed by a GPS receiver where the position is given in latitude and longitude [12].

The data packet from the GPS-Module includes an RMS Header followed by UTC time, data validity checksum, latitude, longitude, velocity, heading, date, magnetic variation and direction, mode, and checksum. The only information required for the proposed system is date, time, latitude and longitude. The GPS modem is interfaced with the microcontroller using the RS-232 communication standard.

D. GPRS-Modem

The general packet radio service (GPRS) is a packet-oriented mobile data service used in 2G and 3G cellular communication systems global system for mobile communications (GSM). The proposed system uses a GPRS-Modem as a communication device to transmit time, date, physical location and level of air pollutants. The modem used for the proposed system has an embedded communication protocol that supports Machine-to-Machine (M2M) intelligent wireless Transmission Control Protocol (TCP/IP) features such as Simple Mail Transfer (SMTP) E-mail, File Transfer Protocol (FTP), and Simple Messaging Service (SMS) services Protocol. The modem supports an RS-232 interface that allows Serial TCP/IP socket tunneling. The modem also has rugged aluminum enclosure making it suitable for the proposed system [12].

E. Pollution-Server

The Pollution-Server is an off-the-shelf standard personal computer with accessibility to the Internet. As Fig. 1 shows, the Pollution-Server connects to the GPRS-Modem via TCP/IP through the Internet and the public mobile network. The server requires a private IP address for the GPRS-Modem and communicates over a pre-configured port. The Pollution-Server connects to a database management system (MySQL) through a local area network (LAN). The Pollution-Server runs a WampServer [13] stack that provides the Apache Web Server in addition to the PHP Server-side scripting language.

Clients such as the municipality, environmental protection agencies, travel agencies, insurance companies and tourist companies can connect to the Pollution-Server through the Internet and check the real-time air pollutants level using a normal browser on a standard PC or a mobile device. The Pollution-Server can be physically located at the Environmental Protection Agency (EPA) or similar government agencies.

IV. Software Architecture

The system software architecture is divided into two layers structure: physical layer and application layer.

A. Physical Layer

This layer is responsible for acquiring the real-time data from the sensors-array and the physical location, time and date of the sampled pollutants from the GPS module. This information is then encapsulated into a data frame by the microcontroller. The microcontroller then sends each frame to the GPRS-Modem through the RS-232 interface. The GPRS-Modem, in turn, sends each data frame to the Pollution-Server using the publicly available mobile network and the Internet.

Unit-ID	Pollution-Server IP-Address	Pollution-Server Port #	Time	Date
Latitude	*Longitude*	CO-Level	NO_2-Level	SO_2-level

Fig. 2. Data-frame payload.

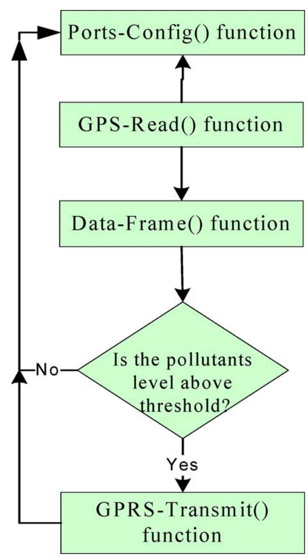

Fig. 3. Mobile-DAQ software algorithm.

The physical layer is implemented using ANSI C language which is compiled to native microcontroller code. The software implementing the physical layer is composed of five functions, namely: Ports-Read() function, Sensor-Acquisition() function, GPS-Position() function, Data-Frame() function, and GPRS-Transmit() function. Are called from a main program that is stored on and executed by the Mobile-DAQ microcontroller.

— Ports-Config() function: Developed to configure the digital inputs/outputs in addition to the resolution of the analog-to-digital converters that read the air pollutants level from sensor array outputs.

— Sensors-Acquisition() function: Reads each pollutant level as a voltage from the signal conditioning circuit output via the built-in analog-to-digital converter module of the microcontroller.

— GPS-Read() function: Communicates with the GPS module through RS-232 and extracts latitude and longitude of the sampled air pollutant along with time and the date.

— Data-Frame() function: Encapsulates the IP address of the Pollution Server, a port number, the three pollutants levels, latitude and longitude of the sampled location, and time and date of the when the samples were taken. The data frame is shown in Fig. 2.

— GPRS-Transmit() function: Selectively sends the data frame to the GPRS-Modem using the RS-232 interface port. This frame is sent according to the algorithm shown in Fig. 3. As the figure shows, a data frame is only transmitted if the pollutant's level has changed since the last reading.

TABLE II
AIR QUALITY DESCRIPTION (MODIFIED FROM [14, TABLEIII])

Index	Air Quality Description	Band
0-100	Clean Air	
101-125	Light Pollution	
126-150	Significant Pollution	
150 above	Heavy Pollution	

B. Application Layer

The application layer consists of three primary modules: *Socket-Server*, *Air-Pollution-Index*, and *Google-Mapper*. Socket-Server collects and stores pollutant data from all the Mobile-DAQs. *AirPollution-Index* calculates pollution categories based on local pollution policies and regulations.

Finally, *Google-Mapper*, makes this pollution information available over the Internet. Each module is described in the following.

— *Socket-Server:* Multithreaded Java program that uses Berkeley sockets to listen to a pre-configured port (e.g., 8080) for socket connections from the various remote Mobile-DAQs. Upon connecting with a Mobile-DAQ, the Socket-Server spawns a software thread that parses the data frame containing pollutant data along with the sampling time and location, stores the data frame in a database using the mySQL database management system and closes the connection.

— *Air-Pollution-Index*: Function to convert the raw pollutant level received from each Mobile-DAQ to pollution standards called air quality index (AQI) using the formula [14]

$$\text{AQI} = \left(\frac{\text{Pollution level}}{\text{Pollution Standard}}\right) * 100 \qquad (1)$$

The pollution standard is defined according the air quality standards of a particular region. For example, in the UAE, the pollutant standard for CO, NO2, and SO2 are 20, 0.15, and 0.13 ppm, respectively. Following [14], the air quality is divided into four categories. An index value of 0–100 corresponds to clean air, 101–125 represent light pollution, 126–150 signify significant pollution, and above 150 means heavy pollution. In summary, the AirPollution-Index function returns a pollution category from the raw pollutant data.

— *Google-Mapper*: PHP program running on the Apache web-server that reads the pollutant data from the mySQL database and plots it on a Google Map using the Google Maps API. In specific, an instance of a GMap object from is created using a JavaScript call. A GPolygon object based on latitude, longitude and the level of the pollutant is created for each region in the Map being shown. The color of the polygon follows the pollution category as calculated by the AirPollution-Index function. For example, for the UAE, a red color is used to denote Heavy Pollution indicating an AQI value of above 150, as shown in the Table II.

This program allows a user to click on a particular polygon representing an area on the map. Upon clicking, the program shows an information window showing the pollution levels of each of CO, NO2, and SO2 in parts per million (ppm), the time of last sampling and hot links to history of each of the gases. Upon clicking a hot link, a user can view the raw ppm values of a gas for that particular location. Fig. 5 shows these readings for the American University of Sharjah in the UAE. Fig. 6 shows sample CO, NO2, and SO2 readings from one of the locations at the university campus.

01	195.229.156.150	8000	11:13:00	01-04-09
25.311103	55.492365	04ppm	0.10ppm	0.05ppm

Fig. 4. Example frame containing pollution and location data.

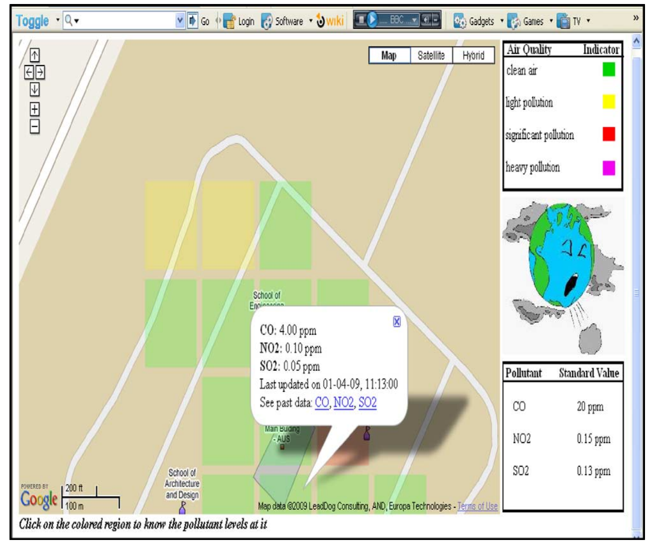

Fig. 5. Public interface showing actual pollutant values.

V. IMPLEMENTATION AND TESTING

The *Environment Protection and Safety Section* (EPSS) in Dubai has monitored air quality since 1988 [14]. Their current system is based on six static monitoring stations located around the Dubai metropolitan area. These stations send air pollutant data to a central server using fixed line modem connections. The pollution data is also available to the public through their Web site. This system has worked well. However, the data collected is limited to the vicinity of the six monitoring stations. Consequently, a mobile system based on the hardware and software architecture described earlier was built and tested in the UAE.

The designed sensor array consisting of CO, NO2, and SO2 was interfaced through a signal conditioning circuit through analogue channels 5, 6, and 7 of the HCS12 microcontroller, as shown in Fig. 1.

The sensor output voltages representing the level of gas for each pollutant (Vg) were converted to a ppm value for each gas. The GPS module was connected to COM0 and the GPRS-Modem was connected to COM1 of the microcontroller. Fig. 4 shows a typical data frame being transmitted from GPRS-Modem to the Pollution-Server.

The Mobile-DAQ was mounted on a University bus that was driven around the campus of the American University of Sharjah (AUS) to collect pollutant data. The Mobile-DAQ was mounted

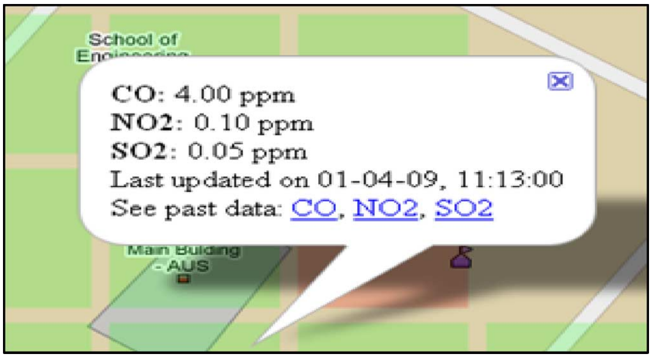

Fig. 6. Details of pollutant data shown in Fig. 5.

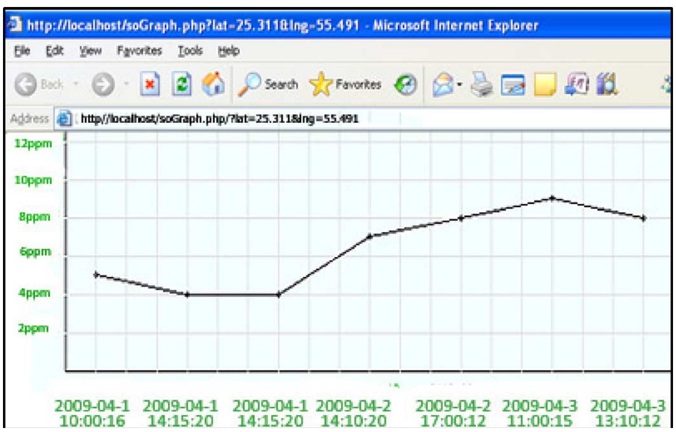

Fig. 7. History of CO pollutant levels.

on top front of the bus to avoid contamination from the bus exhaust. The pollutant data was collected for 12 h. Fig. 6 shows how a user can use the Internet to access pollutant levels in a location covered by the bus. As the figure shows, Google Maps is used as the primary interface. Pollutant data is shown using different colored polygons that are superimposed on the map. The color code used for these polygons was consistent with the AQI index of the Dubai Municipality. As the figure shows, different areas within the American University of Sharjah campus have different levels of pollutants. The yellow polygon shows light pollution while the green polygons show clean air according to the AQI index.

As Fig. 6 shows, a user can click any of the polygons to retrieve details of the various pollutant levels. A user can further drill down by clicking to view the past data for any of the gases for this location. For example, Fig. 7 shows the history of CO pollutant for the last seven readings over an 8 h period for a given day.

VI. Conclusion

A wireless distributed mobile air pollution monitoring system was designed, implemented and tested using the GPRS public network. The system utilizes city buses to collect pollutant gases such as CO, NO2, and SO2. The pollution data from various mobile sensor arrays is transmitted to a central several that make this data available on the Internet through a Google Maps interface. The data shows the pollutant levels and their conformance to local air quality standards. It is worth mentioning that much more work is required to commercialize the system.

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