A Real Time GPRS and Web Based System for Monitoring Air Pollutants using Mobile Data Acquisition unit

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Abstract— A real time Pollutant Monitoring system using an array of GPRS sensors has been designed, implemented and tested. The proposed system consists of a Mobile Data Acquisition Unit (Mobile- DAU) and a fixed internet enabled Pollutant Monitoring Server (P-server). The Mobile-DAU integrates a single-chip microcontroller, air pollutants sensors array, a general packet radio service modem (a GPRS modem), and a Global positioning system module (a GPS module). The P-server is a high end personal computer application server with internet connectivity. The Mobile-DAU gathers air pollutants levels (CO, NO_2, and SO_2), 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 P-Server via the public mobile network. A database server is attached to the P-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 P-server is interfaced to google maps to display real time pollutants levels and locations in large metropolitan areas. The system reports real-time pollutants level and their location on a 24-h/7-day basis.

Key words: GPRS, CO, NO_2, and SO_2

I. Introduction

Many air pollutant systems in urban and rural areas that utilize smart sensor networks and wireless system were reported in recent literature. An environmental air pollution monitoring system that measures CO, NO_2, and SO_2 was reported [1]. The system is based on a smart sensor micro-converter 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 20 sensors and 5 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 Wi-Fi 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 environment parameters 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 based 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 particles, CO2, temperature, and humidity sensors. The system's monitoring range is around 250 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 give 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 pollutant sensors (CO, NO_2, SO_2), General Packet Radio Service (GPRS-Modem), and a global 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 moving, 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 P-Server via the public mobile network. A data- base server is attached to the P-Server for storing the pollutants level for further usage by interested clients such as environment protection agencies, vehicles regeneration authorities, tourists and insurance companies. The P-Server is interfaced to Google maps to display real-time pollutants levels and their locations in large metropolitan areas.

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. Requirements

A system can be recognized by its characteristics i.e. its functional and non-functional requirements. Functional requirements refers to the primary functionality of a system while non-functional requirements describe attributes like reliability, efficiency and security, etc. The system's functional requirements are as follows:

- System must provide accurate and continuous real-time data.
- System needs to store the data and provide access to allocation map interface.
- 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 install deploy.

Nonfunctional requirements for the system indicates that the system is reliable, portable, accurate, maintainable, secure, accessible, and usable and efficient.

III. HARDWARE ARCHITECTURE

Functional and non-functional requirements of the system are satisfied by two major building blocks namely: a Mobile Data-Acquisition Unit (Mobile-DAU) and a fixed Internet-Enabled Pollutant monitoring Server (P-Server). The Mobile-DAU is designed by integrating the hardware modules shown in Fig. 1. As the figure shows, the Mobile-DAU consists of a 16-bit single-chip microcontroller integrated with a sensor array using analog ports. Single-chip microcontroller 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, 4Kbytes of EPROM, 256 Kbytes of FEEPROM, two RS-232 serial communication ports, 4 Control Area Networks ports, SPI communication ports [9]. These resources are sufficient for proposed application.

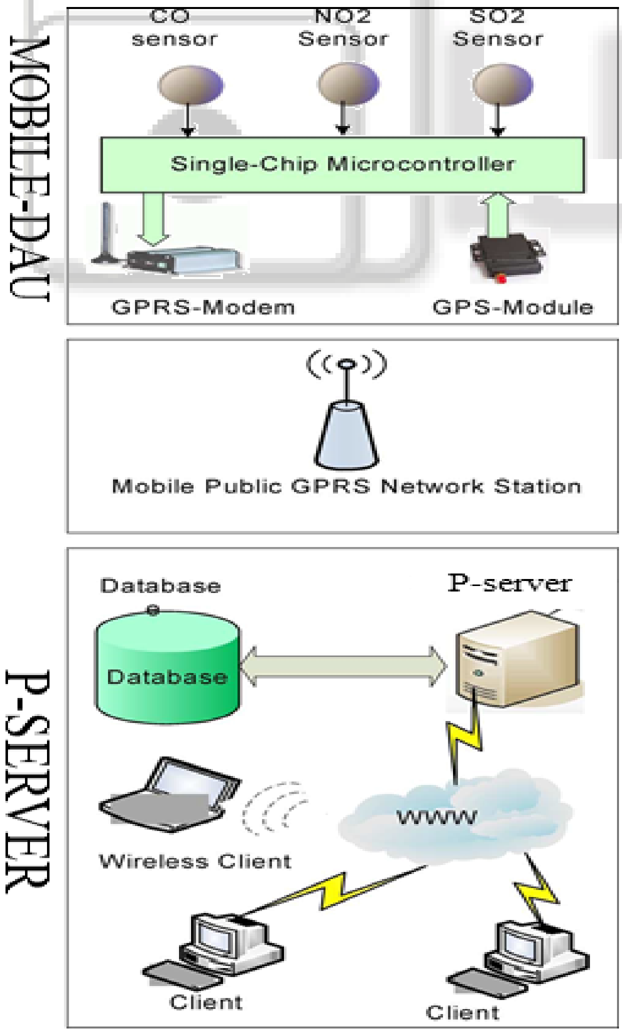

Fig. 1: System hardware basic building blocks.

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

Table 1: Sensor Array Specification

B. Sensors Array:

The sensors array consists of three air pollutants sensors including Carbon Monoxide (CO), Nitrogen Dioxide (NO2), and Sulphur Dioxide (SO2) [10]. As Table I shows, the resolution of these sensors is sufficient for pollutant 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.

C. GPS Module:

The GPS module provides the physical coordinate location of the mobile-DAU, time and date in National Marine Electronics Association (NMEA) format [11]. NEMA format includes the complete position, velocity, and time computed by the GPS receiver where the position is given in latitude and longitude [12]. 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 mobile data service used in 2G and 3G cellular communication systems and 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 which makes it suitable for the proposed system [12].

E. P-Server:

The P-Server is a standard personal computer with accessibility to the Internet. As Fig. 1 shows, the P-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 P-Server connects to a database management system (MySQL) through a local area network (LAN). The P-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 P-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 P-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 pollutants from the GPS module. This information is then stored 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 P-Server using the publicly available mobile network and the Internet.

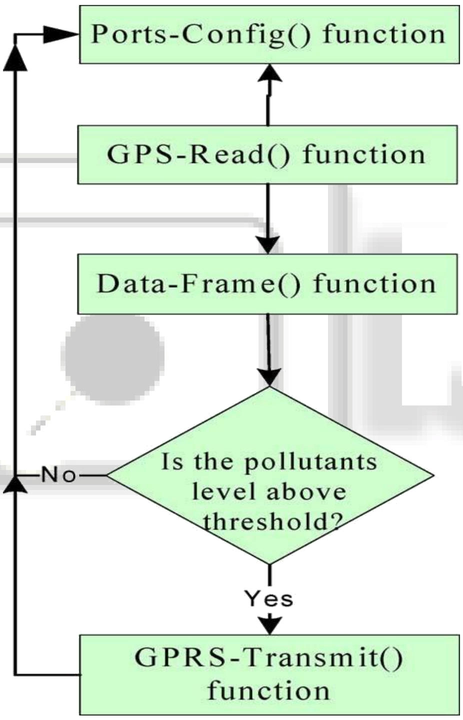

Fig. 2: Mobile- DAU Software Algorithm.

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-Config() function, Sensor-Acquisition() function, GPS-Position() function, Data-Frame() function, and GPRS-Transmit () function. These functions are called from a main program that is stored on and executed by the Mobile-DAU 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.
- 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 date.
- Data-Frame() function: Encapsulates the IP address of the P-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.
- 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. 2. A data frame is only transmitted if the pollutants level has changed since the last reading.

Index	Air quality description	Band
0-100	Clean air	
101-125	Light pollution	
126-150	Significant pollution	
150 above	Heavy pollution	

Table 2: Air Quality Description
(Modified From [14, Table Iii])

B. *Application Layer:*

The application layer consists of three primary modules: Socket-Server, Air-Pollutant-Index, and Google-Mapper. Socket-Server collects and stores pollutant data from all the Mobile-DAU. AirPollution-Index categorises pollution based on local pollution policies and regulations. Finally, Google-Mapper, makes this pollutant information available over the Internet. Each module is described in the following.

- Socket-Server: It is 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-DAUs. Upon connecting with a Mobile-DAU, the Socket-Server evoke a software thread that provide the data frame containing pollutant data along with the sampling time and location, stores the data frame in a database using mySQL database management system and close the connection.
- Air-Pollutant-Index: Its Function is to convert the raw pollutant level received from each Mobile-DAU to pollution standards called air quality index (AQI) using the formula [14]

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

The pollutant 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 Air-Pollutant-Index function returns a pollution category from the raw pollutant data.

Google-Mapper: A PHP program running on the Apache web-server reads the pollutant data from the mySQL database and plots it on a Google Map using the Google Maps application. The color of the polygon follows the pollution category as calculated by the Air-Pollutant-Index function. For example, for 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) as shown in fig.3.

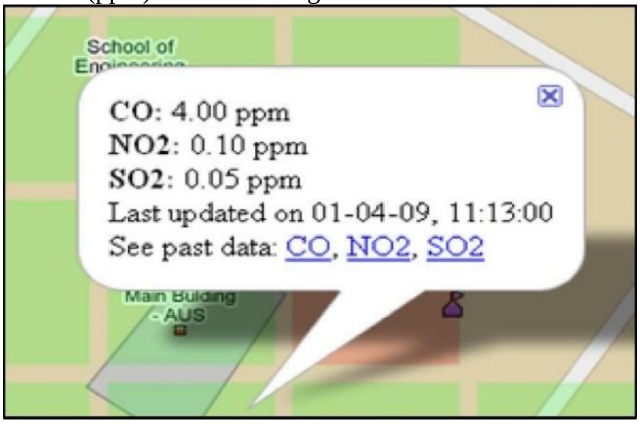

Fig. 3: Details of pollutant data of a particular location

V. IMPLEMENTATION AND TESTING

The environment Protection and Safety Section (EPSS) 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 pollutant data is also available to the public through their Website. 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 is implemented.

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 microcontroller, as shown in Fig. 1.

The sensor output voltages representing the level of gas for each pollutant were converted to a ppm value for each gas. The GPS module was connected to port 0 and the GPRS-Modem was connected to port 1 of the microcontroller. Fig. 1 shows a typical data frame being transmitted from GPRS-Modem to the P-Server. The Mobile-DAU was mounted on a vehicle that was driven around a particular location to collect pollutant data.

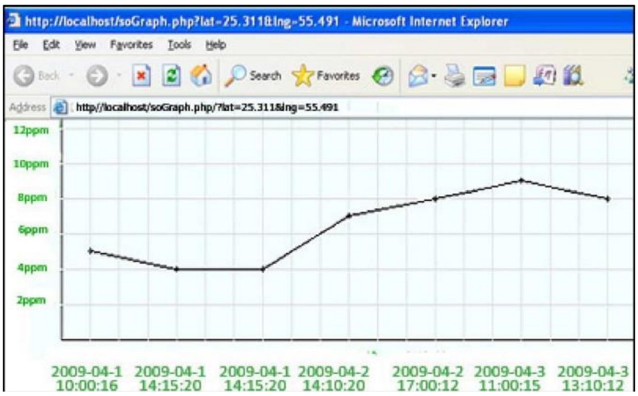

Fig. 4: History of CO pollutant levels.

The pollutant data was collected for 12 h. Fig. 3 shows how a user can use the Internet to access pollutant levels in a location covered by the vehicle. 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 that location.

As fig. 3 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. 4 shows the history of CO pollutant for the last seven readings over an 8 h period for a given day.

So, in this way the system is tested and implemented with the application in providing real time pollutant data on internet where users can access this data easily.

VI. CONCLUSION

A wireless distributed mobile air pollutant monitoring system was designed, implemented and tested using the GPRS public network. The system utilizes vehicles to collect pollutant gases such as CO, NO2, and SO2. The pollution data from various mobile sensor arrays is transmitted to a central server 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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