

PolluMap: A Pollution Mapper for Cities

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Abstract — PolluMap is a new automated system that monitors the air quality of urban cities and displays the information using a web service. The system collects pollution data using mobile hardware modules, transmits the data regularly using GPRS to a back-end server, and integrates the data to generate a pollution map of the city using its geographical information system. The pollution map is available at anytime from an easy-to-view website. Unlike previous pollution mappers, the new system provides continuous update of pollution information in addition to maximum coverage. It can be easily expanded to new areas and is cheap to employ. The system has been implemented and tested in Dubai. Initial results show the effectiveness of the proposed system.

Index Terms — Pollution Mapping, Web Application, GSM, GPRS.

1. INTRODUCTION

Urban pollution monitoring systems can be as well established over the web as the Air Quality Archive [1] that collects regular information about the pollution across UK and displays it to the user. Such a network collects valuable information and enjoys high traffic rates as shown in [2]. These disperse and discrete sensors collect information according to their distribution that reports the air quality. The distribution of these sensors, as suggested in [3], can provide a good coverage of certain geographic zones, but not sufficient to provide continuity in the reported data. An innovative way of collecting the pollution data was proposed by [4]. It proposes a mobile system, being connected to off shelf sensors, that collects pollution data entries when carried around by volunteers or on a pike rack. The system uses the Global Positioning Service (GPS) to attach the geographical coordinates to the data entry. However, the proposed system required updating the database entries by directly connecting the devices to computer stations, which slowed down the synchronization process. This introduces a need to a system that provides continuous data collection and synchronization to establish a fully automatic monitoring system that enjoys the least amount of human interference; the PolluMap.

PolluMap is an automatic Pollution Mapper for urban cities. It collects pollution data entries automatically across a geographical zone to provide a synchronized

database about pollution levels on the web. It gives the user the ability to view the pollution levels as well as their predicted values that are derived from the current patterns of pollution trends.

The mapper is innovative in different aspects:

- System Mobility / Connectivity tradeoff. The PolluMap innovation and usage of a different connectivity mean. The usage of the GPRS to use the GSM coverage to its maximum with an efficient access to the internet on demand.

- System Cost. The cost of covering a large area using new sensors is now out of date, where you can replace this inefficiency by using a mobile and relatively very small number of sensors to do the work of the old huge network of sensors installed across the city.

- System Expandability. System expandability can be undertaken at zero additional cost, by expanding the scheduling of shuttles or changing it instead of adding new sensor units.

- System Target Users. The PolluMap targets the public with the information collected in a graphical manner that translates the readings the system carried out to an easy to view and easy to understand format.

2. POLLUMAP DESIGN

The *PolluMap* high level system design is divided into 3 major components: (1) Data Collection, (2) Data Storage, and (3) Data Presentation. The *data collection* component is responsible for the continuous collection of the pollution data and the reliable transfer of the data to the system storage backbone. The *data storage* component

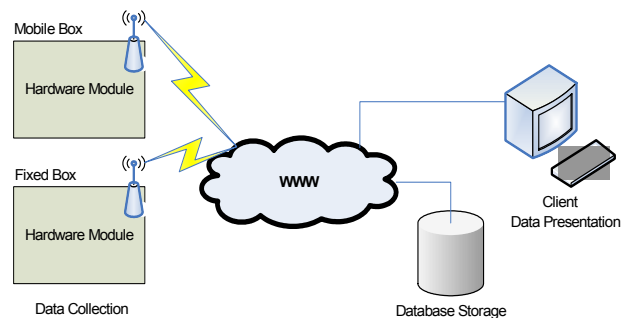


Fig. 1. High Level PolluMap Design

is responsible for the efficient storage and analysis of the collected pollution data and for guaranteeing access by authenticated users only. The *data presentation* component is responsible to allow the end user to easily access and view the pollution information via the World Wide Web (WWW). For a more detailed view of the system's high level design check Fig. 1.

The *data collection* component consists of two main parts: (1) Pollution Data Collection and (2) Pollution Data Transfer. The data collection component is cheap to implement and can be easily expanded to cover new areas without needing to increase the number of sensors. This can be done by simply changing the module carrier schedule to cover the new areas [1], [3]. Data transfer must be frequent and fast to provide the latest pollution information to the end user. This can be achieved by either sending messages over the GSM network or GPRS internet network. Wireless internet technologies can also be used as a low-cost medium to transfer the pollution data.

The *data storage* component implements an efficient database that can handle the large amount of transferred information. It can also handle complex algorithm computations used to plot a map of pollution distribution, provide a history graph of pollution levels, and predict future levels of pollution.

The *data presentation* component provides the end user with an easy-to-use website where the user can, using a single menu click, view the latest pollution information, examine the pollution history in certain areas, and read a mathematical-based predicted estimate of future pollution levels.

3. POLLUMAP HARDWARE

The PolluMap hardware component was selected to tackle the mobility and connectivity tradeoffs shown in previous work [1][4][5]. The PolluMap hardware module is mounted on a mobile unit such as a pre-scheduled shuttles (e.g. city buses) or governmental vehicles. The coverage and efficiency of data collection depends on the schedule of these shuttles. The hardware component tackles three main functionalities handling (1) data collection, (2) local data storage, and (3) data transmission. The main components of the PolluMap hardware are - As shown in Fig. 2:

- 1) Sensors Set (Gases, Temperature, and Humidity) [6].
- 2) Siemens XT55 GPS module [7].
- 3) ATmega32L Microcontroller [8].
- 4) Siemens XT55 GPRS module.

A. Data Acquisition

The Hardware component collects the pollution data using its analog and digital inputs. The input from the gas sensors and temperature/humidity sensors are interfaced

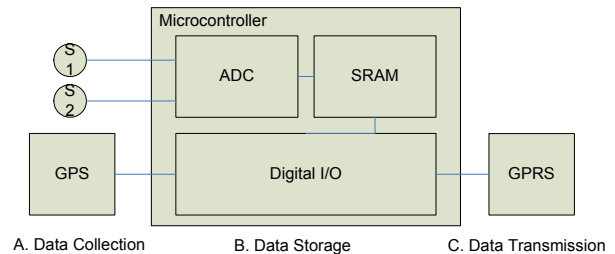


Fig. 2. PolluMap hardware modules structure

with the 8 channel input of the microcontroller. The input is read continuously through the input ports after powering the module. However, the sensors' data are not stored until the GPS unit is initiated and starts giving valid geographic position. When the position becomes valid, the sensors' data are stored in memory as blocks with their corresponding time of reading and location information.

To maintain a safe storage mechanism, a Top-Of-Stack (TOS) pointer keeps track of the last entry's address and indicates reaching the maximum limit of storage which in turn will trigger the reading cycle. The reading cycle can take up to 1 minute at the power up of the module to capture a reading from its cold start (power saving mode). The reading cycle is performed every 1 minute to guarantee a maximum of 2 minutes of time distance between the consecutive read blocks. An interrupt runs to grant this service and do the reads to save the system from continuously running the read cycles.

B. Local Data Storage

The PolluMap hardware unit stores the collected pollution data instances in "pollution snapshots". These snapshots contain the collected data resulting from a successful read cycle initiated by the microcontroller. A snapshot contains the following entries (Table 1)

The data storage in the ATmega32 devices provides a 2KB of SRAM, which means that the memory will take up to 41 blocks of data (ignoring 80B for general program use). The data acquired from the sensors will be attached to the data read from the GPS that contains both the time and geographical position. The GPS GPGGA message will carry the basic location and time information that the system needs to store in the pollution snapshot. The GPGGA message format is defined by NMEA 2.0 and used by the XT55 module used in the hardware implementation. output message and their interpretations.

TABLE I: POLLUTION SNAPSHOT DATA STRUCTURE

Entry	Size	Format	NOTES
Reading ID	1B	0x12	Referenced by TOS
Time	4B	hhmm	From NMEA 2.0
Latitude	8B	ddmm.mmmm	From NMEA 2.0
Longitude	8B	ddmm.mmmm	From NMEA 2.0
NE/NW/SE/SW	1B	Ex. 0x01 (NE)- 0x04(SW)	
S[1..6]	4B*6	0xdddd (float)	ppm (parts per million)
Temperature	1B	0xdd (int)	
Humidity	1B	0xdd (int)	
Total	48B		

C. Data Transmission

Transmitting the collected data takes place in the PolluMap whenever the TOS pointer triggers the sending routine. The indication of a full data stack will start the transmission module through the GPRS interface provided by the XT55 module. The GPRS connection uses the GSM network to establish a connection to the internet using TCP/IP stack. The connection takes place usually in two steps: establishing the connection and transferring data. The connection in PolluMap undergoes three steps: Establish Connection, Authenticate, and send data. The added authentication step improves the security level of the system and allows only authenticated PolluMap pieces to send pollution data to the main server. The authentication is downloaded to the EEPROM to permanently identify the authentication code of the chip that can be recognized by the PolluMap software end.

After connection is established, and the hardware instance is authenticated, the transmission of data starts to carry the pollution snapshots till all the snapshots get sent. The snapshots (48B) will carry the TCP/IP header (20B+20B) and form a transaction total of 3508B. This will help us later in carrying out a financial assessment of the PolluMap design.

4. POLLUMAP SOFTWARE

PolluMap is divided into four individual components, the *Data Acquisition Service* (DAS), the *Map Generation Service* (MGS), the *PolluMap Website*, and the *PolluMap Monitor*. The *Data Acquisition Service* (DAS) is a windows service that is responsible for listening for incoming connections from the PolluMap HD and store the received data in the database. The *Map Generation*

Service is another windows service responsible for generating the pollution map using the latest available data in the database, categorizing the map according to location and time, and saving the map image on the disk. The *PolluMap Website* serves as the front end that directly interacts with the user. The *PolluMap Monitor* takes the duty of monitoring the system and alerting the administrators of any possible failures. This separation of components provides scalability as each component can be started and stopped without depending on the other components. It is also important to mention that it is not required that all the components reside on machine which makes the application much more fault tolerant in cases of machine failure.

A. Data Acquisition Service (DAS)

The DAS is a multithreaded server that handles the connections made by the PolluMap HD. When the service is started it starts listening for TCP/IP connections on a specific port. When any PolluMap HD tries to connect to the server, a thread is created to handle that request and the server returns back to the listening mode to handle any other clients trying to connect. After the thread is created it tries to authenticate the client using a special code unique to each PolluMap HD. This way it can make sure that no malicious users are able to send false data to fool the system or even launch a DOS attack. Upon the authentication of the client the server starts receiving all data from the sensor and storing it in a buffer. The processing is delayed until all the data arrives to minimize the communication time between the server and the client. The thread then extracts different attributes from the received data and stores them in the database. The DAS is designed in a modular way to allow adding sensors to the

system by just adding an entry to the database, in Fig. 3, without any code modifications.

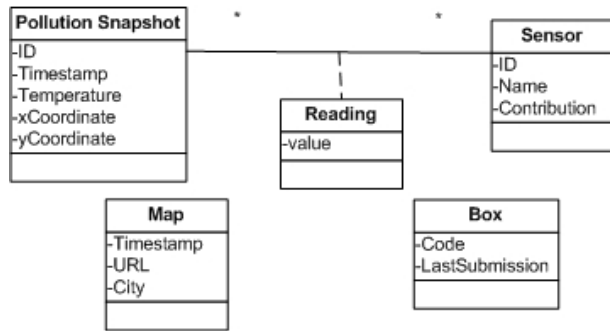


Fig. 3. PolluMap Database design

B. Map Generation Service (MGS)

The MGS is a windows service programmed to generate a pollution map for the city according to the pollution index. To draw the map the service requires two things: a map image and an XML descriptor of the map. The MGS requires the image in order to paint over the different gradients of the index. The XML descriptor contains data about the location of the map (latitude and longitude of the two corners), the number of dividing sections (will be discussed later) and the description of different map areas. Provided with these two files the MGS will be run automatically every ten minutes. During each cycle the MGS will divide the map into X by Y squares according to the descriptor. It will then query the database for the latest five readings in each square. The index of the squares will be set to be the average of all five readings and it will be assigned a color. The MGS afterwards will apply a gradient effect between the squares to achieve a smooth drawing. With this step done the generated image is saved on the Web Server and a link to its location along with a timestamp and the city name will be saved in the database.

The MGS itself is designed in a modular way. It contains three classes. The first class is the MapTools class which handles converting the latitude and longitude points into pixel coordinates on the image. The second class is the DrawingTools which provides the different functionalities of drawing that the MGS needs. The last class is the Main class that handles the flow of data to and from the database and drives the other two classes. With this modular design the system can be deployed to plot maps of different cities without having to do any code modifications.

C. PolluMap Website

The PolluMap Website is the front end that interacts with the user as shown in Fig. 4. The site is programmed using PHP and deployed on an Apache Web Server. The site consists of three main parts: the map viewer, the pollution history graph viewer and the area selector. The other parts of the site are ordinary HTML files that describe the functionality of the site. In order to access the main functionalities of the site the user should go to the map archive page. When the user tries to access that page the site will divide the image into parts according to the XML descriptor described earlier using the GD2 library in PHP.

The image is then displayed to the user so that he can click a part of the map to view. When the part of the map has to be displayed the site will query the database to retrieve the path of the latest pollution map. Afterwards it will be cropped to display the portion the user asked for using the GD2 library. From this page the user is able to view a trend graph of the pollution in that area. When the graph is requested the website queries the database to retrieve the worst pollution levels in each month over the last few years. This data is used as an input to the JpGraph library in PHP to generate the graph image and display it to the user.

D. PolluMap Monitor

The PolluMap Monitor is a program that resides in the tray in Windows that alerts the system administrators of any possible failures in the hardware. The monitor uses different methods to detect failures depending on the part in question. Every twenty minutes the monitor will run a series of tests to detect what part has a possible failure. In the first test the monitor will query the database to check time of the last entry sent from each of the PolluMap HDs. If for a reason the PolluMap HD fails as a whole or the GPRS module fails the program will detect that by noticing that no records have been sent in the past three hours. The monitor will also query the database for the last readings from two different PolluMap HDs that pass through the same square. If the reported values pass a certain threshold the monitor detects that there might be an error in the sensors themselves. When the monitor detects any problems it will alert the user using a sound notification accompanied by a balloon box that describes the possible problem.



Fig. 4. PolluMap Website

5. CONCLUSION

PolluMap extends the urban pollution issue to a new dimension that widens the environmental responsibility to be at the stake of citizens along with the government. *PolluMap* proposes an easy-to-understand interface to the end user that operates on a fully automated platform. The system introduces new stakeholders like tourists and investors to the stage, being affected with the urban pollution variables that will eventually get interested groups to a serious move against unusual levels of pollution. For-example, cleaner cities would (1) attract more tourists and senior citizens (2) drive real-estate values up, (3) provide a safer place for citizens with health problems, and (4) attract investors to open new businesses in the region. Getting such a public service out invites more efforts to fight against pollution increases and to guarantee better air quality to everyone. The implementation of the *PolluMap* have produced a working prototype of the system that can perform regular collection and transmission of data according to the proposed standards suggested, taking in consideration different system limitations. The *PolluMap* has been developed according to a very modular design and extensive testing to ensure its performance. The future expansion of the system can develop future heuristics to predict future levels according to the currently observed trends that can be viewed and developed.

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