



Air pollution monitoring through an Internet-based network of volunteers

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ABSTRACT Pollution of the urban environment is fast becoming a grave threat to urban dwellers as levels of toxicity increase to beyond safe limits. This is especially true in many low- and middle-income nations where the rapid pace of industrialization and development, coupled with fast growing and extremely dense urban centres, are leading to more serious environmental hazards for citizens. These include urban air pollution, which is difficult to tackle, especially in cities or nations where resources are scarce, awareness is minimal and the urban environment is not an issue receiving government attention. This paper describes the development and pilot implementation of the Volunteer Internet-based Environment Watch (VIEW) in two cities in Pakistan. This system, which makes use of volunteers and their personal computers to monitor air pollution, can send valuable local environmental data to a central server for storage and collation. The system was successfully developed and deployed in a relatively small period of time, with a small budget and limited human resources. The paper describes the various decisions and choices made with regard to: accessing funding; the organization; the timeframes and work plan; the choices made with regard to physical deployment of the system; budgeting and other project issues. This pilot in Pakistan could serve as a model for similar efforts in other countries.

KEYWORDS air pollution / Internet / low cost / monitoring / sensor networks / voluntary

I. INTRODUCTION

a. The problem

Environmental degradation is one of the biggest problems humanity currently faces. Air pollution is an important part of this, especially in urban centres. Everyone has a right to know about, and a responsibility to help control, air pollution – along with other threats including greenhouse gas emissions. Given that around one-half of humanity lives in urban areas, it is important that urban environmental degradation, including air pollution, is understood and curtailed. Acquiring the vast amounts of data needed to accomplish this and getting people involved in the process are both major challenges. Moreover, in most nations worldwide it is difficult to implement environmental legislation and ensure the regular monitoring that implementation requires. A cheap and effective monitoring solution is needed.

Many organizations and countries around the world have set up urban environmental monitoring systems to provide the data needed to maintain

or improve air quality, and it is standard practice in high-income nations to have such monitoring systems. For instance, an organization created in 1979, called AIRPARIF, has been tasked by the French government to monitor air quality in the Paris region, and it operates a network of 42 automated air quality monitoring stations spread over a 100-kilometre radius.⁽¹⁾ Similarly, in the Australian province of New South Wales, the Environment Protection Authority of the Department of Environment and Conservation of New South Wales is responsible for monitoring and reporting air quality, and collects data on real-time concentrations of ambient level pollutants from over 30 monitoring sites within the Air Quality Monitoring Network located around the metropolitan areas.⁽²⁾ On a larger scale, the United States Environmental Protection Agency manages the nationwide air quality monitoring programme called AIRNow.⁽³⁾ The AIRNow system monitors a specific set of air pollutants called criteria air pollutants across the United States.⁽⁴⁾

BOX 1
Acronyms used in this paper

| | |
|-------|---|
| DAD: | Data Acquisition Device |
| DAS: | Data Acquisition System |
| DCS: | Data Collation System |
| DTS: | Data Transmission System |
| LUMS: | Lahore University of Management Sciences |
| PTCL: | Pakistan Telecommunications Company Limited |
| VIEW: | Volunteer Internet-based Environment Watch |

Pakistan, like most lower-income countries, lacks an urban air pollution monitoring infrastructure and it is difficult for the public sector to dedicate the kind of money and resources necessary for this.⁽⁵⁾ What is required is a system that is comprehensive in terms of spatial and pollutant coverage and is relatively inexpensive and autonomous. This is where the Volunteer Internet-based Environment Watch (VIEW) comes in because it allows almost real-time monitoring of air quality conditions in most urban settings. The current demonstration version of VIEW monitors such basic environmental variables as temperature, humidity and airborne outdoor pollutants (currently carbon monoxide). The system is intended to serve the needs of two groups. The first group is environmental policy makers, workers and activists, and they will be able to:

- create policies and act according to the information they acquire (i.e. they will be able to deploy resources more efficiently and effectively in order to combat pollution); and
- monitor the effects of their policies and actions on the urban environment and fine tune their policies accordingly.

The second group is ordinary citizens, who are empowered through knowledge about the environmental conditions they live in and consequently can act upon that knowledge.

b. Idea, experiment and research

The idea is fairly straightforward. Plug-and-play environment-monitoring devices (or data acquisition devices – DAD) for personal computers have

1. The Automatic Network operated by AIRPARIF, accessible at <http://www.airparif.asso.fr/english/reseau/reseau>.

2. Environment Protection Authority of the Department of Environment and Conservation of New South Wales (2003), Air Quality Data, 19 March, Government of Australia, accessible at <http://www.epa.nsw.gov.au/air/airdata.htm>.

3. United States Environmental Protection Agency (2004), AIRNow Homepage, accessible at <http://www.epa.gov/airnow/index.html>.

4. United States Environmental Protection Agency (2004), Air Pollution Monitoring, accessible at www.epa.gov/oar/oaqps/montring.html#standards.htm.

5. Sheikh, M Omer (2005), "Air quality monitoring: a global perspective", Technical Report, Lahore University of Management Sciences, January, Lahore, Pakistan, page 18.

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been developed and distributed to volunteers. Whenever a volunteer logs on to the Internet, the DAD sends environmental data to a central server for storage and collation. In this way, a regular and comprehensive source of pollution data can be compiled. Given the spread of the Internet around the world, we have potentially a “pollution map” of most of the urbanized planet (Figures 1 and 2). Anyone on the Internet can access data from the central server for a comprehensive pollution analysis of his or her locality, city, country, region or the world. This system was implemented at the Lahore University of Management Sciences (LUMS) over one year, spanning 2004–2005, for the cities of Lahore and Islamabad.

c. Innovations in VIEW

There are four basic avenues of innovation in this system:

- **Use of existing infrastructure.** The system relies on the Internet, which confers two immediate benefits. First, the Internet is a well-established medium of communication – thus VIEW would ride on

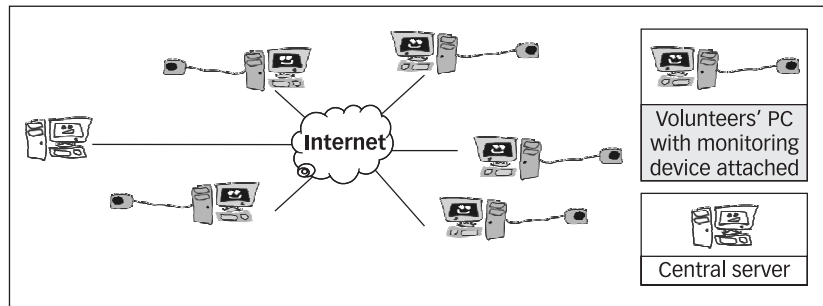


FIGURE 1
Monitoring devices connected to volunteers' computers, which transfer collected information to a central location via the Internet

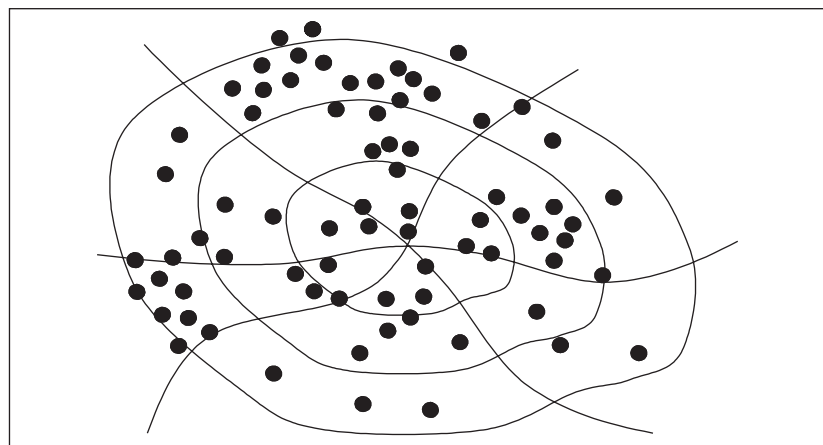


FIGURE 2
Monitoring devices spread across a city (mimicking the spread of internet nodes)

a very reliable infrastructure. Second, because the Internet already exists, the cost of VIEW is relatively low – no new communications infrastructure needs to be developed. A basic assumption here is that a considerable number of urban households have access to the Internet and that urban areas have a good spread of Internet nodes (even in most low- and middle-income countries).

- **Social innovation.** This system relies on volunteers connected to the Internet – potentially most urban dwellers. Consequently, it could get many people directly involved in environmental issues. Most people are aware that their world is being polluted but they are not directly and constantly aware of the danger. Using VIEW, people would have access to all kinds of pollution information, allowing them to see objectively the effects of their choices and actions. VIEW could empower people and communities and allow them to take charge of their environmental fate. A consequence of this might be increased use and improvements in this technology, as people's interest in it grows.
- **Scalability.** Another innovative aspect of VIEW is its scalability. Theoretically, the system could be as big as the Internet itself, which is still growing. In fact, VIEW would take advantage of the concentration of Internet nodes – i.e. the more nodes in a locality, the better the data resolution. So there is great potential for growth in this system.
- **Flexibility.** VIEW is flexible in that any kind of pollutant could be measured depending on the kind of DAD a volunteer acquires. This allows potentially for a comprehensive analysis of the pollution spectrum to take place – the greater the variety of monitoring devices, the better the analysis of the spectrum of pollutants.

d. Paper purpose and structure

This paper describes the project that implemented VIEW over the course of the year starting September 2004 and ending August 2005. Having provided a brief overview of what VIEW is, the rest of the paper sets out in some detail how the project was structured, managed and implemented. The team at LUMS carried out a small-scale pilot, demonstrating the workability of the concept, technologies and deployment. Along with a description of how the project was carried out, this paper also provides recommendations based on our experiences. As with all projects, this one had a significant element of learning, and certain aspects had the potential for a positive adjustment.

Section II sets out the cost estimates for the project and describes how funding was acquired. Section III looks at the organization of the team and the personnel employed, along with the physical infrastructure requirements and provisions. Section IV highlights major design choices and technological innovations made in the VIEW system. Section V highlights the methodology of distributing the system's physical infrastructure to volunteers in two Pakistani cities.

II. PROJECT COSTS AND FUNDING

a. Source of funding and project budget

In 2004, the Pakistan Telecommunications Company Limited (PTCL) launched its Thematic Research Grants Programme. These were small-scale, easy and relatively quick-to-access grants that ranged up to about US\$ 33,333⁽⁶⁾ and lasted up to two years.

The project was planned on a small scale, with costs kept to a minimum, and was to be completed in the span of a year. The budget, as outlined in Table 1, was sent to the PTCL in the proposal.

6. Grants up to 2 million Pakistani rupees (PKR). The US\$ conversion rate is based on US\$ 1 = PKR 60.

TABLE 1
Original project budget

| Major heads | Funding requested (US\$) | Funding acquired (US\$) |
|---------------------------------|--------------------------|-------------------------|
| Equipment – hardware (total): | 6,333 | 6,333 |
| • Personal computer × 2 | 1,667 | 1,667 |
| • Hardware | 833 | 833 |
| • Sensors | 3,833 | 3,833 |
| Equipment – stationery/supplies | 167 | 167 |
| Overhead costs – transportation | 167 | 167 |
| Salaries (total): | 12,800 | 7,233 |
| • PI (salary/honorarium) | 4,000 | 600 |
| • RAs | 8,000 | 6,000 |
| • Technician | 800 | 600 |
| Audit Fee | 389 | 278 |
| Total | 20,000* | 14,200* |

* Figures rounded up.

N.B. The proposal was made in Pakistani rupees although the table presents the amounts in US\$.

The two major costs incurred by the project were salaries (about 64 per cent of the project budget) and equipment (most of the remainder, at 32 per cent.)

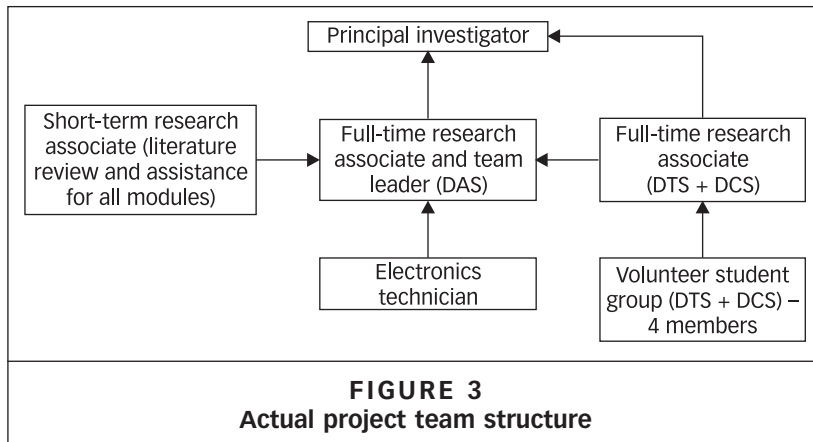
b. Final adjustments to budget

The actual sum acquired from the PTCL was about US\$ 14,200. This changed the circumstances somewhat, as we had originally budgeted for almost US\$ 20,000. The main reductions in the downsized budget were made to salaries, while the sum requested for hardware, stationery and transport remained unaltered.

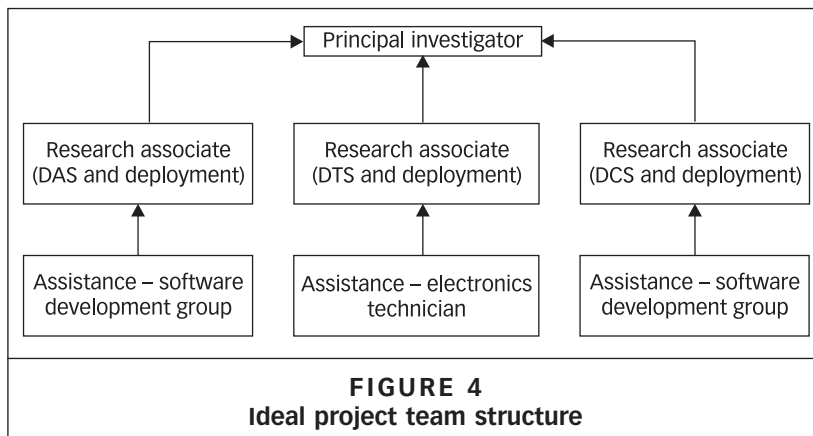
III. PROJECT TEAM, STRUCTURE, SCHEDULE AND INFRASTRUCTURE

a. Team members and structure

Figure 3 outlines the project team organization. The team consisted of a principal investigator, three research associates, a technician and student volunteers. The principal investigator, Dr Muhammad Jahangir Ikram, was the overall head of the project and authorized the purchasing of equipment, hardware and software. He also provided overall guidance to the project and was the primary liaison with the PTCL.



The three research associates reported to Dr Ikram. Ideally, they would have stayed full-time for the duration of the project but this was unaffordable. (An ideal project team structure is given in Figure 4.) Due to funding limitations, we altered our plan to include only two full-duration research associates and one four-month research associate. This modified plan worked well because VIEW is a highly modular system, and consequently the three main components can be prioritized or de-prioritized based on the kinds of constraints faced (funding, personnel, time) and the degree of work required for each system component.



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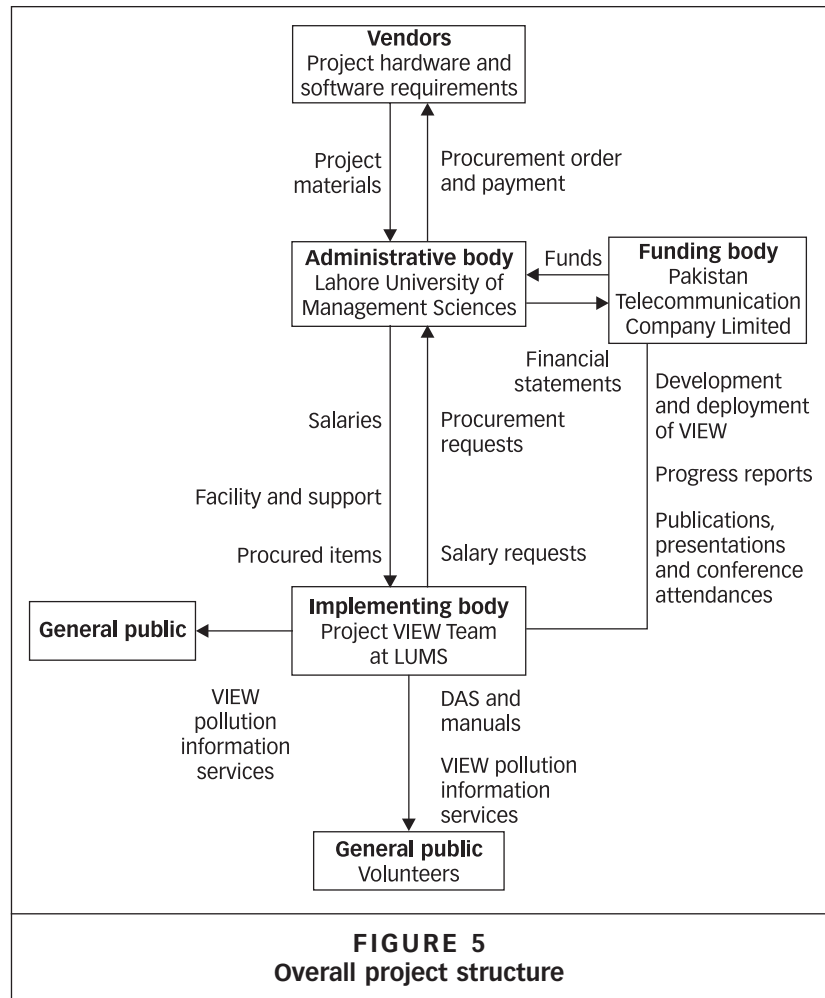
The VIEW project had a very large hardware component in the form of its monitoring stations. Hiring a technician proved useful as he had a good working knowledge of the electronics markets and the manufacturing facilities in Lahore, as well as knowledge of component prices and the latest technologies available.

We also enlisted a group of student volunteers – a useful and much-needed strategy. Specifically, we required additional help in the development of the analysis and collation software, as it was large and quite complex. This student group reported directly to the research associate in charge of the data collation system (DCS) and data transmission system (DTS) (Figure 3).

b. Project structure

The overall structure of the project is provided in Figure 5. All project procurements were processed through LUMS, as this allowed for a check on the items bought.⁽⁷⁾

7. LUMS has a number of established links for the procurement of various supplies (computers, laboratory equipment, stationery, software etc). Consequently, going through LUMS greatly facilitated the procurement requirements for the project.



Since LUMS was administering the fund, it was responsible for providing detailed financial statements to the PTCL. Since the PTCL was to provide money in three separate tranches, with the final two depending upon performance evaluations, it was likely that there would be gaps in the cash flow, which was the case. LUMS was able to bridge these periods, ensuring that salaries and procurement payments were made in a timely fashion.

The team of research associates, students and faculty at LUMS (outlined above) was directly responsible for implementing the VIEW project, which translated into the production of various software and hardware for the system and the eventual deployment of monitoring hardware to volunteers. Another major product made available by the VIEW team to the general public was the provision of urban air pollution monitoring services via the project website on the Internet.

The VIEW team was also responsible for a series of progress reports to the PTCL, mainly through a set of presentations to the PTCL technical monitoring and auditing staff. Finally, the VIEW team was responsible for communicating the experiences, knowledge gained and issues to the scientific community at large, and in this regard a paper was published by the project and presented at two conferences.⁽⁸⁾

c. Project infrastructure

As a science and technology institution, LUMS offered all the facilities needed to implement VIEW—both in terms of physical infrastructure and support personnel. One of the major concerns was the production of the pollution-monitoring hardware. Basic tools, manufacturing facilities and testing equipment were required, along with personnel who could support and supplement the work done by the core VIEW team. LUMS has a fully functioning electronics and systems laboratory with trained technicians proficient in electronics (production and testing). A lot of important propriety software was made available to the project through this laboratory – procuring this software independently for the project would have proved quite costly.

IV. SYSTEM DESIGN AND TECHNOLOGY

This section outlines the design and technology choices for the system. Since this is not intended to be a technical report, only salient design choices will be highlighted and discussed in relation to the broader goals of the project. The VIEW project is intended as a model for other parties interested in similar work, and the basic architecture of the system should be retained (as described later) However, the implementation of this system, i.e. the choice of which software and hardware technologies to employ, should be governed by:

- **what the project can afford:** obviously, the technologies that can be employed depend to a large extent on budgetary constraints;
- **the kind of expertise the project team has:** the capacity of the institution chosen to implement VIEW and the capabilities of the personnel there will define the kinds of technologies chosen. In

8. The paper was presented at the International Conference on Information and Communications Technology held at the Institute for Business Administration in Karachi in August 2005; also at the International Conference on E-governance held at LUMS in Lahore in December 2005. It is titled "A low-cost solution for urban air pollution monitoring using existing infrastructure and loosely coupled ground-based sensing equipment", and was authored by Agha Ali Akram, Dr Muhammad Jahangir Ikram and Mannan Amin. It is a technical report on the project, and details the design choices and technologies used.

the case of the VIEW project, the focus was on the development of monitoring hardware and analysis software, as the expertise of the team leaned in that direction; and

- **the sorts of technologies available:** the availability of technology is linked very closely to project costs. Although any sort of technology can be purchased over the Internet, shipping restrictions and costs will limit availability. Consequently, technologies that are more readily available from local markets need to be chosen. In the case of the VIEW project for instance, PCs were chosen rather than Apple or other standards, as PC compatibles are widely supported in Pakistan and the software is more easily available.

The basic architecture of the system has three core components (Figure 6):

- **data acquisition system (DAS):** hardware units with accompanying software distributed to volunteers, which monitor and acquire environmental data;
- **data transmission system (DTS):** software that allows for data gathered by the DAS to be transmitted to the central server over the Internet; and
- **data collation system (DCS):** software that allows data gathered at the central server to be stored, organized, analyzed and visualized.

a. System design overview

Traditionally, such systems would have developed software in terms of client-side and server-side software, and indeed even VIEW can be conceptualized in these terms.⁹⁾ However, by breaking the system down into three independent functional modules, the complexity, cost and functionality of the system can be fine tuned. For instance, the current DTS relies on the Internet and can use a protocol as simple as a File Transfer Protocol transfer. However, as wireless technologies gain popularity as cheap and reliable mediums of communication, the DTS can start to rely on them as well. The present conceptualization allows for advances in various technologies of relevance to the individual components (i.e. DAS, DTS and DCS) to be incorporated without having to replace outdated functioning components. Thus, for instance, an older version of the DAS can still operate and communicate with a newer version of the DTS, irrespective of the technologies being employed in either.

The design also allows project strengths to be focused on components that match project team strengths. For instance, in our case, the DTS was a low priority sub-system of the VIEW system. This was a deliberate choice as the major team strengths lay in the development of monitoring hardware (i.e. DAS) and analysis software (i.e. DCS – for which we also acquired the help of a student group). In fact, de-prioritizing the DTS also ran parallel to the overall ethos of the VIEW system, whereby an existing, reliable and easy-to-use communications infrastructure i.e. the Internet, was used to relay information from the monitoring stations to the analysis software. Basing the work done on the DTS on this notion, we used existing services and software to simply transfer our data from one end to the other.

9. Fedra, Kurt (1999), "Urban environmental management: monitoring, GIS and modelling", in *Computer, Environment and Urban Systems* Vol 23, pages 443–457, accessible at <http://www.ess.co.at/docs/papers/udm.pdf>.

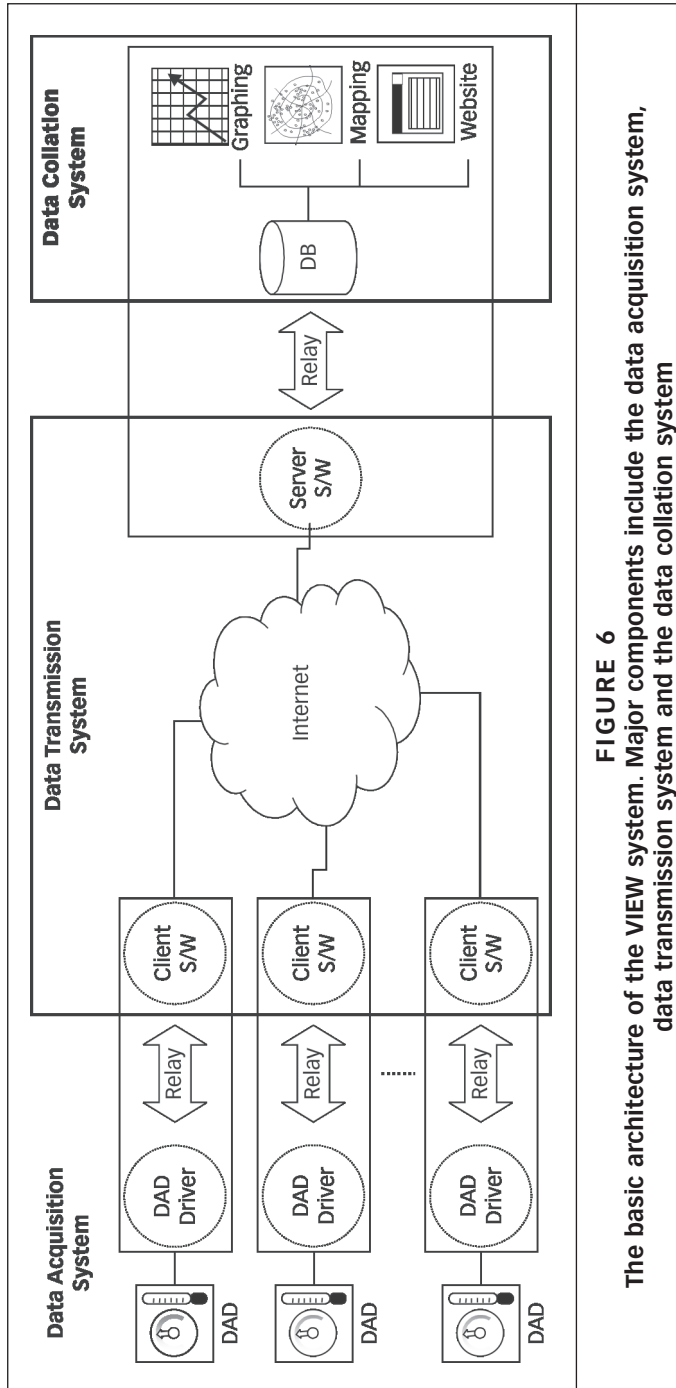


FIGURE 6
The basic architecture of the VIEW system. Major components include the data acquisition system, data transmission system and the data collation system

b. Data acquisition system

Design choices for the DAS. The DAS is the part of VIEW that acquires environmental data and prepares it for transmission. It is a two-component system with a data acquisition device (DAD) and a DAD Driver.

The DAD is a hardware component, the basic design of which is laid out in Figure 7. The heart of the DAD is the 8051 micro-controller, which is quite inexpensive, has a great deal of support available locally in Pakistan and also allows for C language-based software development (a requirement of large-scale projects). The micro-controller directs the basic functioning of the DAD. No extra memory was added in order to reduce the cost of the overall unit and maximize spending on the sensors.

Two sensors form the core-sensing capabilities of the DAD:

- The Sensirion SHT11 is a digital humidity and temperature combo-sensor⁽¹⁰⁾ and interfaces directly with the DAD. It was chosen because it provided a direct digital output, was compact and provided accurate information on basic environmental variables i.e. humidity and temperature. However, with its “surface mount technology” (SMT), the SHT11 proved quite difficult for our technician to handle. We would recommend instead the SHT17, a variant that comes pre-mounted and which is far easier to handle. However, we would recommend the use of the Sensirion sensors as they are reputedly good and relatively cheap.
- The Figaro TGS822 is an analogue carbon monoxide sensor⁽¹¹⁾ that interfaces with the DAD via an Analog to Digital Converter. It is a general-purpose toxic gas sensor that detects the presence of a number of gases that form what are called volatile organic compounds, along with carbon monoxide. This was fit for our purposes. The TGS822 relies on what is called electro-chemical technology, which is relatively cheaper than other sensor technologies. The drawback is that it may not be as accurate. Still, it served our purposes in demonstrating the workability of the VIEW system.

10. Sensirion, The Sensor Company, “SHT1x / SHT7x – humidity and temperature sensor”, accessible at http://www.sensirion.com/en/pdf/Datasheet_SHT1x_SHT7x.pdf.

11. Figaro, “TGS 822”, Product Documentation, accessible at <http://www.figarosensor.com/products/822pdf.pdf>.

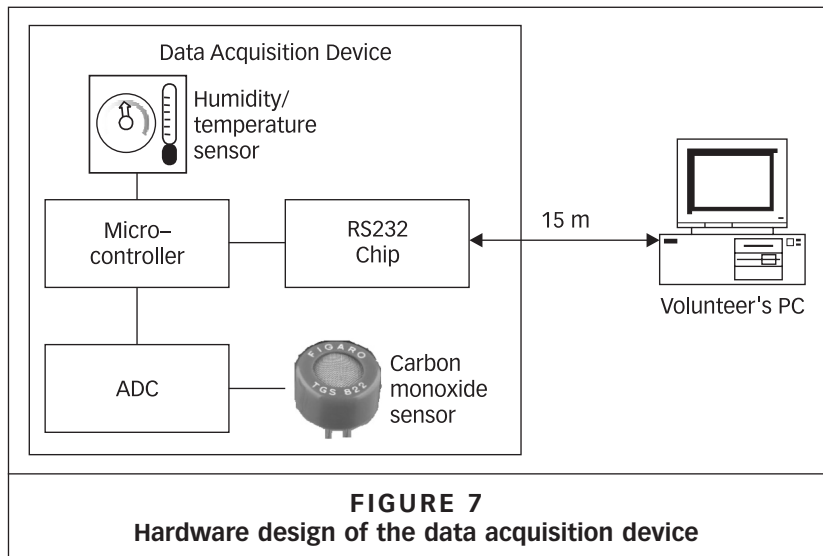


FIGURE 7
Hardware design of the data acquisition device

These sensors were polled regularly over the course of the sampling period to build an average value that was stored at the end of the sampling period. The DAD interfaces with a volunteer's PC through a serial port. The serial port's RS232 medium is a good choice in that it is available on all PCs and that at low baud rates the length of the cable can be substantial (as long as 3,000 feet), thus providing enough length for placement of the DAD module at the most environmentally suitable location.

Due to the memory limitation, a volunteer is required to switch on the PC periodically (for example, once a day), in order for the DAD to transfer its accumulated sensor data to the PC. Once the PC is switched on, the DAD Driver on the PC regularly requests the DAD to transfer all data to the PC as long as the PC is on. The transferred data is subsequently converted into an Extended Mark-up Language (XML) file. XML was chosen as it is fast becoming an industry standard for data communication and offers a simple and robust data storage format. If new data come in from the DAD, it is appended to the XML file and then set aside until a time when the DTS can transfer it to the server.

Implications of the design choices on DAS costs. As the only item that required a real investment in hardware, the DADs posed the only real production cost for the entire system. The cost breakdown is set out in Table 2.

| Item | Cost (US\$) |
|--|-------------|
| SHT11 | 21 |
| TGS822 | 10 |
| Supporting hardware (cables, power supply, micro-controller and support electronics) | 14 |
| Total | 45 |

For the VIEW project to be demonstrated as workable, the TGS822 was sufficient. However, Figaro makes other sensors designed specially for detecting exhaust fumes from gasoline engines (Figaro TGS 2201 Gasoline and Diesel Exhaust Sensor) and sensors dedicated to measuring carbon dioxide and carbon monoxide (Figaro TGS 2442 Carbon Monoxide Sensor). Depending on the availability of funding, higher-quality sensing options could be considered. We also contacted City Technology, who manufacture high-accuracy sensing components but at a cost 10 to 20 times higher than the Figaro. For a project like VIEW, the number of sensing units deployed compensates for the slightly lower level of accuracy of the Figaro sensors.

In order to monitor a greater number of pollutant categories, a corresponding number of sensors would need to be employed, adding to the cost of the system. One idea was to distribute different kinds of monitoring stations to volunteers according to a preset priority. Close to 188 toxic air pollutants have been identified,⁽¹²⁾ however, according to the US Environmental Protection Agency, there is a specific set of air pollutants called "criteria air pollutants" that are known for their adverse effects on human health as well as on the surrounding environment.⁽¹³⁾

12. United States Environmental Protection Agency, "About air toxics, health and ecological effects", accessible at <http://www.epa.gov/air/toxicair/newtoxics.html>.

13. See reference 4.

14. Setting standards for maximum permissible levels of particulate matter in the air recognizes that it is the smaller particles that are more dangerous to health. Thus standards are set not for "total suspended particulates" but for particles that are smaller than 10 microns (PM₁₀) and for particles that are smaller than 2.5 microns (PM_{2.5}).

15. This idea has been incorporated into a follow-up design for VIEW, called VIEW-2. More information on this will be available once VIEW-2 is up and running but the basic idea is to have a few high-quality/high-expense sensors at a few select locations, using a more instant communications infrastructure (mobile telephony, for example).

16. The project URL was bought for a year and was www.viewpk.info.

These pollutants include carbon monoxide (CO), nitrogen dioxide (NO₂), sulphur dioxide (SO₂), ozone (O₃), particulate matter (PM₁₀ and PM_{2.5})⁽¹⁴⁾ and lead (Pb). Depending on the priority given to the measurement of a particular pollutant category, the number of monitoring stations can be varied. For example, if a total of 100 monitoring stations are to be built, and the priority-designated pollutant is carbon monoxide, then 60 or 70 out of the 100 stations built could monitor carbon monoxide, while the remaining would monitor other categories.

It should be noted that off-the-shelf sensors cannot measure certain categories of pollutants. Specifically, particulate matter and lead require more expensive and specialized equipment. For a system that claims to be low cost, measurement of these pollutants could pose a cost problem. One solution is simply to have fewer of the lead and particulate sensors but to have them as high-priority acquisition nodes.⁽¹⁵⁾

c. Data transmission system

The DTS is responsible for picking up and transferring information gathered by the DAS from a volunteer's PC to the VIEW server over the Internet. As noted already, the team's make-up and expertise meant that the DTS was kept as a low priority sub-system of VIEW. Its software was kept relatively simple and used the File Transfer Protocol to transfer data to the server, encapsulated in an XML file. The File Transfer Protocol is a standardized and easily available service and consequently was the obvious choice for our project.

d. Data collation system

The DCS, the storage and analysis component of VIEW, has the following four functions:

- **XML to database data transfer:** the DCS regularly collects raw data from each XML file received by the server and integrates it into the sensor-reading database with all the previous data. Thus, whereas each XML file is a temporal snapshot of the environmental conditions in each device's locality, the database contains a seamless aggregate of all past readings. This raw data bank is the source for almost all the analyses that are conducted;
- **node management:** this is the server-side software that is used to register each DAD at a given location, and it is accessible only to an authorized operator. Information about a volunteer's address, her/his name, phone number and e-mail address are stored in a database. In case of device malfunction, this software automatically alerts both the volunteer and the DCS operator by e-mail;
- **analysis** (maps, graphs and tables): this can be accessed by anyone and is available on the VIEW website.⁽¹⁶⁾ The analysis component is described in some depth in the following section; and
- **account management:** accounts are maintained for the three types of user (operator, privileged user and ordinary user). Information on new users is stored and maintained in the user account database.

e. Data analysis

Because the system was intended to provide citizens with key information on pollution in their cities, the analysis methods needed to be easily understood. It was therefore vital that a simple and highly intuitive set of analysis tools be developed. The primary analysis tools are visual, since these best indicate the correlation between quality of the environment and pollution levels.

The following key methods of analysis were selected.

- **Trend graphs.** Trend graph analysis provides a quick look at variations in pollution over time. The user specifies a city area, the pollution variable and a time frame. The result is a 2-axis graph that is generated at run time by the system. Users of the system use trend graph analysis to help them visualize the degree of pollution in areas of interest to them. For example, a user may wish to determine variations in air pollution over the course of a week in her or his area of work in order to gauge personal levels of exposure.
- **Interpolated area map.** The map analysis is the most visual and intuitive of the three types of analysis available. The interpolated area map allows a bird's eye visualization of the quantities of an air pollutant across a specific location in the city selected. The two cities we chose for such analysis were Lahore and Islamabad and the pollutant we monitored was carbon monoxide.

The interpolated area map uses city maps. In our case, we simply scanned scaled maps of Lahore and Islamabad and used these as backgrounds on which to overlay pollution analyses. Ideally, GPS-based maps or Geographic Information Systems ought to be used. However, the solution we came up with was just as effective and far cheaper to implement. Scanning readily available scaled maps of cities allows the basic geography of a city to be visualized. Overlaying this with our analysis, i.e. colour-coded pollution levels, gives the user a very good idea of pollution levels in different areas of the city.

This tool utilizes simple colour-coding schemes to highlight the degree of pollution in a geographic space. In our case, we had a spectrum of colours that ran from blue (low pollution) to red (highly polluted) as this seemed intuitive and easy. However, numerous other schemes exist. One of the more creative ones we came across was the ATMO-France guide, which uses 10 colours to represent levels of air pollution, going from light blue (very good) through green, yellow and orange to red (very poor). The ATMO air quality index for Paris air is calculated according to French national standards and identifies the typical characteristics of overall air quality for the whole of the Paris region. This index is determined using levels of pollution measured throughout the course of the day by urban and peri-urban stations for background pollution in the city.⁽¹⁷⁾ The ATMO air quality index is published at 5 pm every evening, it is broadcast on TV and radio and it is made available to the public on the front page of the AIRPARIF website.⁽¹⁸⁾

To generate a map, an environmental variable is chosen and a function (average, maximum and minimum) is applied to it for the interval of time specified by the user. The variable is colour coded to match its varying intensities across sensor locations. The final map generated is a spatially interpolated colour-coded one. Carbon monoxide levels were colour

17. AIRPARIF, ATMO air quality index, accessible at <http://www.airparif.asso.fr/english/indices/atmo.htm>.

18. AIRPARIF, Homepage, accessible at <http://www.airparif.asso.fr/english/index.php>.

coded to allow for easy interpretation of the map visualization. Values at the DAD nodes were interpolated to allow for a smooth transition of data. This map feature also allows for zooming in and out in order to obtain pollution spectrum maps for different areas in a city.

Another important aspect of the analysis tools is the fact that they are available online (for instance, the interpolated area map is shown within the Internet Explorer web browser). All the analysis services were provided as online tools – users could generate their own analysis while sitting at home (or wherever they choose to access the Internet), by accessing the DCS over the Internet using a standard web browser.

Area data tables. This is the most “flexible” of the data analysis options. The user can select any given area, time frame and sensor type, and the result is a table of that area’s data for that device for the given area for the given time. This function is provided for statisticians and researchers who wish to generate their own analyses using raw data.

This option appears less intuitive than the others but has deliberately been included in order that more serious researchers may reap the benefits of the information provided by VIEW.

V. DEPLOYMENT

a. Deployment: scale and process

A relatively small-scale deployment was planned as VIEW was a demonstration project. A total of 55 working and fully tested DADs were manufactured. Of these, 13 were deployed in the city of Lahore and eight were deployed in Islamabad. This fell short of the target quantity of at least 30 in Lahore and at least 20 in Islamabad (an overall target of 50 DADs to be deployed).

It was decided that the best way to deploy the DAS would be to recruit volunteers from within LUMS, as the student body hailed from a variety of locations within Lahore, had PCs with Internet connections and, furthermore, were likely to be more sympathetic to the idea. So DADs were handed out to a network of friends and associates of the VIEW team from within LUMS as and when a suitable volunteer was located.

The final deployment package given to a volunteer included the DAD outdoor unit, the power and communications module and a volunteer’s handbook.

The volunteer’s handbook was produced to help volunteers install the DAD. It outlined the basic concept of VIEW, how to physically install the DAD and also how to operate its software. The volunteers were also guided in the use of the online analysis tools (i.e. the DCS).

b. Challenges in deployment

The main challenges in the deployment phase were issues with the server, the installation of monitoring stations at volunteers’ homes and the locations of monitoring hardware.

Running and maintaining a server turned out to be more complex than we had anticipated. Initially, the VIEW server was placed behind the LUMS firewall as we felt that this would provide the maximum amount of protection. However, because volunteers’ computers would transmit files

to the VIEW server for collation, specific ports had to be left “open”. As it turned out, leaving these ports open meant that our server was susceptible to virus attacks and would end up “flooding” the LUMS network. Every time this happened, our server was disabled and taken off the network. Therefore, to allow for the transfer of files to the server from volunteers’ computers over the Internet, the VIEW server had to be made external to the LUMS network. This also meant that the server was outside the protection provided by the LUMS network firewall. Our server software was updated, along with its virus protection software, but the server was still susceptible to attack and its down-time was quite high. The ideal solution would probably be to host the VIEW server via a professional facility in order that virus protection be kept up-to-date and the server’s down-time be kept to a minimum. An alternative would be to hire a full-time system administrator to maintain the existing server – as in the case of the DAS where we had a dedicated technician for manufacturing and testing. However, this would add significantly to costs.

The other major deployment issue was the installation of the DAS. The hardware component of the DAS, i.e. the DAD, was built to minimize costs, which implied the most basic set of technologies. One implication of keeping things basic was that the DAD’s outdoor unit was connected to a volunteer’s PC via a long cable, which would have to go from the outside to the inside of a house. Modern homes typically have insulated or sealed windows that do not allow a cable to pass through, and installation often meant finding an appropriate gap. The solution, of course, would be to make the DAD outdoor unit more autonomous in terms of its power requirements and also in terms of communications. A plausible solution would be to use wireless communications technologies, and solar-charged battery packs on the DAD outdoor unit – but these would be fairly expensive and would add significantly to the development time.

Finally, we were concerned about the spread of the DADs we distributed, i.e. how many DADs in which area. We had intended to deploy 50 units in Lahore and 30 in Islamabad, with the obvious constraint of needing a PC with Internet connectivity wherever a DAD was to be deployed. Since we deployed our hardware through a network of colleagues at LUMS, the spatial distribution of the monitoring equipment was not an even spread. The overall deployment fell short of the targeted total of 50 DADs. Unforeseen and unavoidable problems arose given that the project budget was limited. Should anyone choose to undertake this sort of project, VIEW can provide valuable lessons especially with regard to deployment.

VI. POTENTIAL: THE FUTURE OF VIEW

VIEW demonstrates that a low-cost solution to urban air pollution monitoring is possible using existing infrastructure, but the work we have done is just the beginning. Limitations in the work were primarily technological in nature and a function of cost. The following are potential areas of further research and improvement:

- for the DAS, system resources could be increased for prolonged data accumulation before transmission, which would mean a less frequent need for volunteers to connect to the Internet;
- power features could be improved with the provision of an onboard uninterrupted power source. Most cities in Pakistan see frequent

power outages and this would allow the DAD to continue acquiring data even in times of power outages;

- one of the basic premises of VIEW is the use of existing infrastructure. Consequently, the DTS relies on the Internet. However, as progress is made in wireless technologies, the DTS could begin migrating to wireless platforms;
- the DCS could be tied to Geographic Information System software, more accurate geo-referencing and more accurate and detailed contour maps. The current version of the DCS uses scanned map images and relies on visual correspondence for locating DAD units; and
- VIEW's inherent flexibility could be exploited to yield a greater variety of data types. Besides urban air pollution monitoring, with a little bit of work VIEW has the following potential capabilities:
 - water quality monitoring – this would require the development of a water-testing and monitoring DAS;
 - weather – to determine the microclimate of urban centres. This would require the development of weather instrumentation for the DAS; and
 - other types of pollution – e.g. noise pollution, light pollution, radioactivity levels (especially relevant in urban contexts with nuclear power plants).

A follow-up project is now being developed called the Volunteer Internet-based Environment Watch 2 (VIEW-2). A proposal was drafted and sent to the PTCL in January 2006. VIEW-2 will look to tackle some of the deficiencies of the original VIEW project, which were predominantly technological. A larger sum of money has been requested for a larger scale deployment and improvements in data acquisition, quality and analysis. It is hoped that with these improvements in technology, the information provided by the VIEW system will be more accessible to the public at large and the government.

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