BVG Trust

J. Sci. Trans. Environ. Technov. 2011, 5(1) :7 - 14

Scientific Transactions in Environment and Technovation

Research Articles

Design of physical topology in sensor network for an industrial air pollution monitoring

P. Velmani[1]* and K. Ramar[2]

[1]Department of Computer Science, The M.D.T. Hindu College, Tirunelveli, Tamil Nadu, India.

[2]Department of Computer Science and Engineering, National Engineering College, Kovilpatti, Tamil Nadu, India.

Abstract

Environmental sensor network is a new way of monitoring the environment to get reliable information and exposure over time. Pollution monitoring in industrial area fall under environmental data collection in sensor network. The air quality data statistics available today is being recognized to be more indicative rather than absolute and perfect. We explore the scope to deploy Sensor Network (SN), for an air pollution monitoring system by operating a network of continuous monitoring equipment around the clock at industrial sites, with the goal of collecting complete and accurate air quality data. Designing an efficient application is one of the major challenges and sensor network challenges are application dependent. Within this scope, an efficient physical topology design considerations of sensor network for an industrial air pollution monitoring system has been reported in this paper.

Keywords: air pollution, air quality, environmental sensor network, industrial air pollution monitoring, physical topology design

INTRODUCTION

Recently, Sensor Networks (SN) promise to revolutionize sensing in a wide range of application domains, due to their speed, reliability, accuracy, flexibility and ease of deployment. Sensor network enable information gathering, information processing and reliable monitoring (Tubaishat and Madria, 2003). Environmental sensor network is a new way of monitoring the environment. They comprise sensor nodes in the environment that record real-time data, which are retrieved, analyzed and integrated with other data sets to predict the future. The real success of the sensor network technology depends mainly on its application in correcting a harmful situation or in maintaining a good one. Concern for the environmental pollution is a prospective application domain which is of particular value to our earth. In the review paper of Garcia - Hernandez *et al.*, (2007), it is pointed that industrial applications of sensor network are monitoring and controlling industrial equipment, factory process controlling, industrial automation and manufacturing monitoring. In addition to that, to maintain a clean and green environment, it is proposed to form SN for industrial air pollution level monitoring.

To construct an efficient air pollution monitoring sensor network in an industrial area, application domain space and network domain space are the two avenues to be considered. Without thorough knowledge of the application domain, one cannot design an effective SN. In SN design, physical and logical topology plays major role. The physical topology refers to the configuration of connection between peripherals involved in the network like sensor, computer and transmission media. The logical topology is a method used to pass information between them. In this paper, the possibilities of physical topology design of building an efficient data collecting system for continuous air pollution level monitoring using SN in an industrial area, with available resources, are discussed.

SOURCES OF AIR POLLUTION AND THEIR MODELS

Large cities with high concentration of industry, intensive transport networks and high population density are major sources of air pollution. Predicting air quality from multiple sources(Fig1) is very complicated. So, air quality models are best used for isolated sources or situations (Balram, 2007). Table 1 shows the classifications of air pollution models by their applications (Cheremisinoff, 1989). For all the models, environmentalists want to collect data from a large number of sensors spread throughout the area and then analyze the data offline (Mainwaring *et al.*, 2002). The environmentalist would be interested in collecting data over several months or years in order to look for long term trends. For the data to be meaningful it must be collected at regular intervals and node would remain at known locations.

*Corresponding Author
email: *vel_comp@yahoo.com*

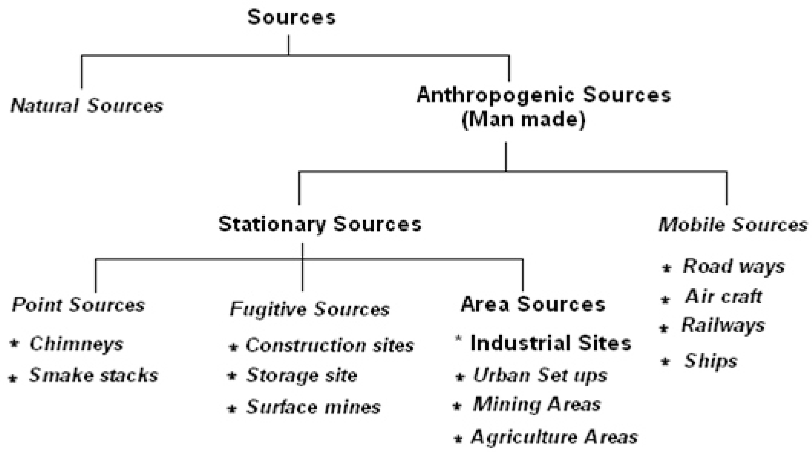

Figure 1. Sources of Air Pollution

Table 1. Classification of Air Pollution Models by Their Applications

Category of Use	Purpose
Scientific research	To acquire knowledge about basic atmospheric processes To prove new theories To educate
Air management and Decision making	To incorporate air quality constraints into the planning System of land-use and transportation
Air Pollution control	To develop control strategies To forecast and warn To extend the information system
Environmental impact	To provide environmental modeling with an air pollution sub-model To study the impact of air pollution from new sources
Air pollution episodes	To create an alert system for air pollution episodes (in Japan an alert system is in operation in several areas) To specify endangered areas in case of air pollution incidents (e.g., Chernobyl accident)

MOTIVATIONS TO THIS STUDY

■ Living green and clean is a global expectation. Due to the lack and delay in implementing certain regulations in both government and private sector industries, threat of global warming is increasing.

■ Air monitoring equipment is not something new, but the integration of this technology with existing Information Technology (IT) operations is new and necessary to keep a pollution free environment.

■ The air quality monitoring is already undertaken to detect any deterioration in air quality arising from residential, industrial and vehicular sources of pollution. National Air Quality Monitoring Programme (NAMP), Global Environmental Monitoring System (GEMS), World Health Organization (WHO) and World Bank Programme are some of the monitoring programmes in India. The major thrust of the Ministry of Environment is to control pollution and take stringent actions against the polluting industrial units (Salpekar *et al.*, 2006; CPCB, 2003).

■ The air quality data generation through air quality monitoring network available today, involves large number of monitoring agencies, personal and equipment sampling, chemical analysis and data reporting etc. The involvement of several agencies increases the probability of variations on the data. Therefore, air quality data statistics is being recognized to be more indicative rather than absolute and perfect (Salpekar *et al.*, 2006).

■ Centre for Science and Environment, New Delhi (India), has Green Rating Programme (GRP), to rate industries based on their environmental performance. Information for the programme is collected directly from the industries as well as from other secondary sources such as State Pollution Control Board, local news papers and NGOs (CSE, New Delhi. 2008) . It is also reported that the Clean Development Mechanism (CDM) meant to tackle climate change is unclean and corrupt (Narain, 2008).

With the increasing pace of industrialization all over the world, the need for continuous monitoring of air pollution due to industrial growth has become significant. World Bank report says "India has 4.5 million small and medium enterprises which contribute 40 percent of the industrial production but create 70 percent of the industrial pollution" (Yadav, 2008). It is seen that, the gain of the product is comparable to the cost, to make up the effect of industrial pollution. Therefore, it is necessary to monitor and control air pollution round the clock using SN.

From literature survey, it is understood that, most of the previous research deals with air pollution monitoring from vehicular source or collective sources. For example,

• Develop low-cost and ubiquitous sensor network to collect real-time large scale and comprehensive environmental data from road traffic emissions for air pollution monitoring in urban environment (Yajiema *et al*, 2008).

• Taxi drivers were provided with a dash mounted Global Positioning System (GPS) device and a tube to hang from their passenger window. The tube contained a carbon monoxide sensor. This study is used to collect actual air quality sensor data by citizens across an urban landscape (Geneva:WHO, 2006).

• Geo sensor network designed to measure data related to geo spatial information. It could be useful to detect the conditions of remote place as a new instrument for environmental monitoring in the physical world. It employs the context model for understanding the status of air pollution in the current and near future area (Jung *et al.*, 2008).

• Sensor technologies designed to collect and relay information about specific events (BC CARMS, 2006).

• In Washington, every day, on and above Earth, millions of sensors collect vast amounts of data representing interactions among the planet's systems of land, air, water and life. This is the kind of data needed to address the complexities of climate change or a move to a low-carbon-dioxide world economy, but gathering it is just the first step (Pellerin, 2009).

• To develop risk free residential and industrial areas in Europe and to cover large monitoring area, sensor is placed in the luggage compartment of a glider (Schreiner *et al*, 2006).

• Health risk assessments are also analyzed in some papers. (Anjaneyulu *et al*, 2005; Opera and Dunea, 2009).

In essence, the drawback of existing air pollution monitoring methods and limited study on industrial air pollution monitoring have motivated this study.

SENSOR NETWORK DESIGN SPACE

To design an efficient air pollution monitoring sensor network in an industrial area, application domain space and network domain space are the two avenues to be considered. Application domain space deals with the suitable choices of key evaluation metrics of SN for an application and network domain space deals with the important parameters that influence the SN design.

Application Domain space

Sensor network incorporates technologies from three different research components such as sensing, computing and communication. Within the field of environmental sensor network, domain knowledge is an essential fourth component (Martinez *et al.*, 2004). Another view is, critique in the field of wireless sensor network domain falls in to two main distinct categories: Algorithms and protocols & Application centric system design (Raman *et al.*, 2008). So, without thorough knowledge of the application domain, one cannot design an effective SN.

The general characteristics and choices of sensor network design space for an application, are discussed, in our survey paper (Velmani *et al.*, 2008) on the basis of Romer *et al.*, (2004) and the problems in existing pollution monitoring scenario based on Tamil Nadu Pollution Control Board (TNPCB), India are also reported. The suitable choices of domain space for Industrial Air Pollution Monitoring (IAPM)) are analyzed in another paper (Velmani *et al.*, 2009), with the key evaluation metrics for SN. For ready reference, the characteristics choice of IAPM application is listed in Table (2). The conclusions are based on the analysis of the various sensors available in TNPCB in certain districts and some large scale industries.

Network Domain Space

Conceptually, the network domain space comes next to application domain space. The design of the sensor network is influenced by Fault tolerance, Scalability, Production cost, Operating environment, Topology,

Table 2. Characteristics choice of IAPM Application

Characteristics	Suitable choice
Deployment	Manual, Onetime
Sensor Size	Desktop A4 to a rack of two feet
Mobility	Immobile
Cost	1 lakh to 40 lakhs (installed in Thoothukudi-TamiNadu-(India)
Resource	Battery power
Node type	Heterogeneous
Communication mode	Wired/Wireless
Network type	Infrastructure
Coverage	Dense
Connectivity	Always connected
Network size	Depends on the number of sensors
Life time	Several years
Topology	Hierarchical Tree
Other Quality Of Service (QOS)	Real time constraints, data reliability, Querying ability, effective sample rate, security etc.

Hardware constraints, Transmission media and Power consumption (Akyildiz *et al.*, 2002). When selecting a network configuration, topology (physical and logical) plays major role. Hence, three layer network domain spaces proposed are

- Construction of optimized Sensor field and sensor network design (Physical topology)

- Networking protocol (Logical topology)

- Application level performance analysis.

To improve the performance of the network, optimizations across three layers are to be analyzed.

PHYSICAL TOPOLOGY

In sensor network, the infrastructure plays a significant role in determining the performance of the network. The physical topology of a network in terms of generic architecture of SN in IAPM, sample sensor field design, and sensor's marshalling panel setup are discussed in this section.

Generic architecture of SN in IAPM

Generic architecture of Industrial air pollution monitoring through Internet is shown in Figure 2. Server in industrial premises (micro server) is used for getting data from sensor node and it can also combine data from different sensor nodes in a sensor field. PCB use Internet or mobile device for downloading the sensor data from various industrial zones through server in their premise (Meta server). Meta server is necessary for monitoring of hazardous air pollutants in and around industrial areas and to identify and control critically polluting areas.

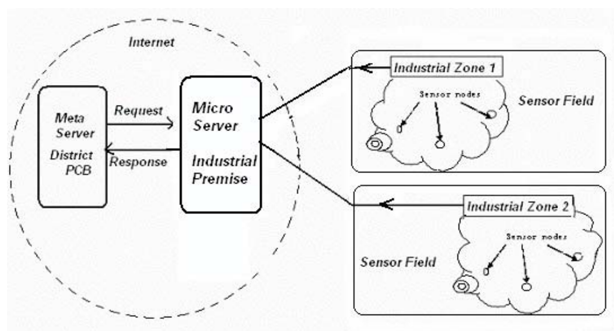

Figure 2. Generic Architecture of SN in IAPM through Internet

For efficient implementation of District Industrial Air Pollution Network (DIAPNET), district is divided into several industrial zones. One industrial zone may be treated as one sensor field. A sensor field is an area which contains many sensor nodes doing the same work. This application may have high performance analyzers to monitor various pollutant gases. The typical job of an analyzer (Sensor node) is to sense the environment, collect data and route the data. A network is used to pass the data to micro server and then to meta server.

The above network is a kind of distributed sensor networks, to gather data and communicate it to an uplink point. The information gathered by a particular sensor does not influence the behavior of another sensor. In other words, distributed sensors collect data, while sensor webs are self-informing and modify their behavior on the basis of collective data (BC CARMS, 2006).

Configuration of connections between nodes namely distance between nodes, physical interconnections, transmission rates, and/or signal types are the parameters that also affect actual physical network

Sample sensor field design

Sensor field design itself is a complex one in this application. Before any system is designed and installed, a detailed understanding of its physical environment and deployment is required. Deployment means node distribution within the phenomenon field that is, deployment strategy. Three deployment strategies (Tilak *et al.*, 2002) are random deployment, regular deployment and planned deployment. This application requires planned deployment. To target emissions from specific industrial area, number of sensors and their location are important. To decide sensor's location, the following spatial and background knowledge (CPCB, 2003; CAMP, 2007 and Sivertsen, 2008) are necessary.

- Pollution affects inside the industry first and then outside. To maintain the permissible levels of certain pollutant in the work environment and to indicate horrific levels, sensors must be fixed inside industrial premise such as chimneys place and other work place (number of units available in an industry).
- As per TNPCB norms outdoor air quality around industrial area must be measured in a 10km radius.
- Predominant wind directions and seasonal variations in temperature play an important role in determining location of monitoring stations. The monitoring stations should be located in areas that are downwind from the sources, which met the criteria for a good site.
- It is meaningless to fix all outdoor sensors at the fence line of an industry or exact 10km radius as per PCB norms, because the concentrations at the fence line of a facility are not necessarily the maximum concentrations.
- Emission rate may vary from day to day due to changes in the production rate.

Figure 3. shows sample topo sketch of air quality monitoring sensor locations in XYZ industry. Sensors numbered 1-4 are fixed at various units (indoor location) of an industry namely Chlorine Based Product Division (CBPD), Caustic Soda Division (CSD), Poly Vinyl Chloride Resin Division (PVCRD), Iron Oxide Division (IOD) and Thermal Power Division (TPD) and sensors numbered 5-7 are fixed at outdoor location namely Industry entrance, nearby residence area and business complex.

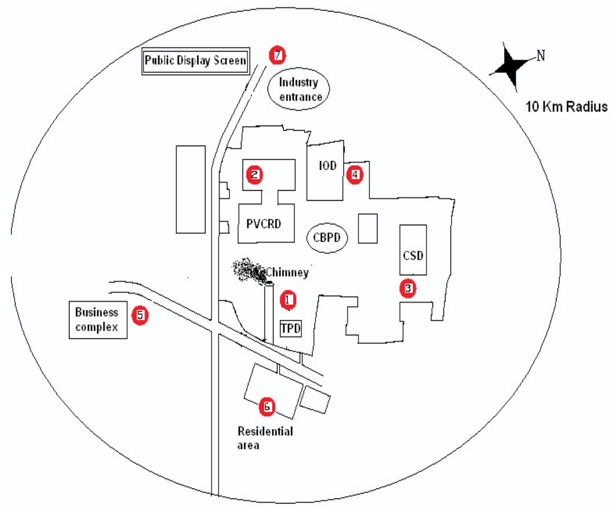

Figure 3. Topo sketch showing Air Quality Monitoring Sensor locations in XYZ industry

To assist an industrialist, an expert system should be developed to fix the exact number and distribution of monitoring locations of a sensor. Direction and distance from source, sensor's capability are the important phenomena to be considered for sensor field design. After deciding the number of sensors and their location the next step is possible communication mode. Due to the physical environment, wireless networks often extend to an existing wired infrastructure. The wired infrastructure may be quite complex to begin with, especially if it spans several buildings in a campus setting. Wireless networks depend on having a solid, stable, well-designed wired network in place. If the existing wired network is not stable, another choice is the wireless. Most of the industries, especially large scale industries are equipped with hard wire cables. So, for cost effective SN in industrial air pollution monitoring, already available wired network may be utilized. If possible Wireless LAN or GSM network for long distance communication may be used. Thus data passes anywhere, that is, to a micro server for better scheme in production activities, and to a meta server for taking action against industry and analyzing air quality.

Sensor's Marshalling Panel (SMP)

Large scale industries are having Industrial Control Systems namely Distributed control system (DCS) to form communication network of various critical infrastructures of electric, water, oil/gas, chemicals, pipelines, and transportation. In addition to that it is proposed to form a separate sensor's marshalling panel to collect data from various sensors available in different units.

For example, Figure 4. shows sensor's marshalling panel connecting five different units like CBPD, CSD, PVCRD, IOD and TPD of an industry. Sensors are numbered from S1 to Sn. Instead of the traditional DCS, now cost effective digital communication networks are available, to improve plant performance (ISA Headlines. 2007). There is substantial hardware installation savings associated with field bus system compared to a traditional DCS installation in terms of terminations, number of I/O cards, home run wiring, number of transmitters, control room instrument panel space.

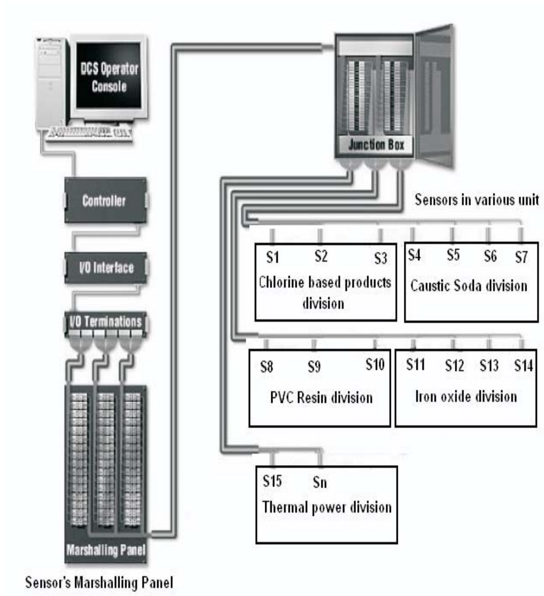

Figure 4. Sensor's Marshalling Panel

TOPOLOGY MAINTENANCE ISSUES

The issues related to topology maintenance are considered in three phases (Akyildiz *et al.*, 2002)

• **Predeployment & deployment:** Position of a sensor is required to make sense of the reported data.

• **Post deployment:** Topology changes are attributed to both node mobility and failure. In this application nodes are immobile and not clustered. So there is no chance of failure due to jamming, obstacles etc.

• **Redeployment of additional nodes:** The following cases may be considered for the updating of new nodes.

♦ **Extension of existing industrial zone** (increase in the number of sensors in a sensor field)

♦ **Implementing new industrial zone** (increase in the number of sensor field)

♦ **As the network ages, it is expected that the node will fail over time.** Instrumentation experts from a large-scale industry reported that, sensor's life degrades if high concentrated polluted gas is observed by a sensor. (Replace failure sensor in a sensor field).

In all the above three cases, the changes are in the sensor field. And also, there is no chance of reconfiguration, and will not represent a significant amount of the overall system energy usage. After deployment, the nodes must first discover the topology of the network and estimate optimal routing strategies (Ganesan *et al.*, 2002). The routing strategy can then be used to route data to a central collection points. In environmental monitoring applications, it is not essential that the nodes develop the optimal routing strategies on their own. Instead, it may be possible to calculate the optimal routing topology outside the network and then communicate necessary information to the nodes as required. This is possible because the physical topology of the network is stable.

Data collected by sensors must be passed to micro server and then to meta server (District PCB). It may also extend to State PCB and then to Central PCB. So, it is concluded that the nature of this application is, fixed sensor nodes with static physical topology namely hierarchical tree topology with the following characteristics.

• Number of siblings (Sensors in an industrial area) differs in each sensor field.

• Distance and direction from a sensor to a micro server (in industrial premises) may vary.

• Every sensor field is considered as a sub tree and server in industrial premises is known as the root of the sub tree.

• Number of sensor field in an industrial area or zone may vary.

• Sensor field form star topology (connect all sensors to the micro server).

Considerations when choosing a topology are cost of implementation and future growth. QOS requirement analysis based on this application is the next step.

CONCLUSION

The purpose of the industrial air pollution monitoring study is to gather real data. To collect absolute and perfect air quality data, continuous air monitoring using sensor network is the only solution. As a first step, this paper deals with the physical design considerations of sensor network with focus on sensor network model, sample sensor field design and sensor's marshalling unit. The design methodology mentioned can be very useful for management and control of environmental pollution, to ensure a pollution free environment and also to get real picture of air pollution models.

The characteristics of this application are large-scale and long-lived, fixed sensor nodes, static physical topology, cost-driven and no delay in control. The energetic collaboration between users, application domain experts, hardware engineers and software developers are needed to implement an efficient system.

REFERENCES

Akyildiz Ian, F., Weilian Su., Yogesh Sankarasubramaniam., Erdal Cayirci and Georiga. 2002. A survey on sensor networks. *IEEE communications Magazine*, August, P. 102-114.

Anjaneyulu, Y., Jayakumar, I., Hima Bindu, V., Sagareswar, G., Mukunda Roa, P.V., Rambabu, N., Ramani, K.V. 2005. Use of multi-objective air pollution monitoring sites and online air pollution monitoring system for total health risk assessment in Hyderabad, India. International *J. Environmental Research Public Health*, 2: 343-354.

Balram Pani. 2007. *Text book of environmental chemistry.* I. K. International Publishing House Pvt. Ltd, New Delhi. P. 197-198.

BC CARMS 2006. *In Situ* Sensors, Sensor Networks and Webs – Industry and Market Overview.

CAMP (Collegeville Air Monitoring Project). 2007. Public meeting report. Pennsylvania. http://www.dep.state.pa.us/dep/deputate/airwaste/aq/toxics/toxics.htm

Cheremisinoff, Paul, N. 1989. *Air pollution Control: Encyclopedia of environmental control technology.* Gulf Publishing Company, volume 2. P. 86.

CPCB (Central Pollution Control Board). 2003. Ministry of environment and forest, New Delhi. Guidelines for ambient air quality monitoring. http://www.cpcb.nic.in

CSE (Centre for Science and Environment), New Delhi. 2008. Advertisement. Green Rating network. Science and Environment fortnightly. *Down To Earth*, Dec. 16, P.51.

Ganesan Deepak, Bhaskar Krishnamacharii., Alec Woo., David E. Culler., Deborah Estrin. and Stephen Wicer. 2002. Complex behavior at scale: An experimental study of low-power wireless sensor network. Technical Report UCLA/CSD – TR., 02 – 0013.

Garcia-Hernandez Carlos F. 2007. Pablo H.bargiiengoytia-gunzalez., Joaquin Garcia-Hernandez., Jesus A. Perez-Diaz. 2007. Wireless sensor networks and applications: a survey. *IJCSNS*, 7: 264-273.

Geneva: WHO. 2006. Environmental monitoring with mobile phones- World Health Organization air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: global update 2005, P.52-54.

ISA Headlines. 2007. WEquipment and controls & Delta.V. *Comparing a Deltav tm system with Foundation tm field bus to a DCS – Technical article*. 15:8-14.

Jung Young Jin, Yang Koo Lee., Dong Gyu Lee., Keun Ho Ryu., Silvia Nittel. 2008. Air pollution monitoring system based on geo sensor network. IGARRS, Boston.

Mainwaring Alan, M., David, E., Culler, Joseph Polastre, Robert Szewczyk., John Anderson. 2002. Wireless sensor networks for Habitat Monitoring, proc. *ACM International workshop on Wireless sensor networks and applications (WSNA'02). Atlanta, Georgia, USA.* P. 88-97.

Martinez Kirk., Jane, K., Hart., Royan Ong. 2004. Environmental sensor network. C*omputer*, 37: 50-56.

Narain Sunita, 2008. Cover story- Carbon Discredit. Science and Environment fortnightly, *Down To Earth*, 17: 41.

Opera, Mihaela and Dunea, Daniel. 2009. An Environmental Dianosis Expert system. *Workshop Proc. AIAI*, P. 291-302.

Pellerin Cheryl, 2009. Planetary Skin - Tool Aims to Improve Response to Climate Change. Planetary Skin news 19 march, NASA, Cisco collaborate to integrate climate data. *Web technology.*

Raman, Bhaskaran, Kameswari Chebrolu. 2008. Censor networks: A critique of sensor networks from a systems perspective. ACM SIGCOMM Computer Communication Review, 38:75-78.

Romer Kay, Friedemann Mattern, Eth Zurich. 2004. The design space of wireless sensor networks. *IEEE Wireless communications,* December, P. 54-61.

Salpekar, A., Kadambari Sharma, Bharatia Khadi, Gramodyog., Vikas Abhikaran. 2006. *Encyclopedia of Ecology and Environment.* New Delhi, 8:36- 37.

Schreiner.C., Branzila.M.,Trandabat.A., Clobanu.R.C. 2006. Air quality pollution mapping system using remote measurement & GPS Technology. *Global NEST* . 8: 315-323.

Sivertsen Bjarne, 2008. Monitoring air quality, objectives and design. Chemical Industry and Chemical Engineering CI&CE quarterly. 14: 167-171.

Tilak, Sameer, Nael, B., Abu-Ghazaleh., Wendi Heinzelman. 2002. Infrastructure Tradeoffs for sensor networks. WSNA, September, 28, Atlanda, Georgia, USA, P.49-58.

Tubaishat, Malik and Sanjay Madria. 2003. Sensor networks: An overview. *IEEE Potentials* April/May, P. 20-23.

Velmani, P., Ramar, K. 2008. A survey on implementing sensor networking in industrial air pollution monitoring. *Proc. of NACIPAN*, P. 136-142.

Velmani, P., Ramar, K. 2009. Application domain space of sensor network in industrial air pollution monitoring - A study. *Proc. of ICONCT*. P. 197-202.

Yadav, Nivit Kumar. 2008. Reporters diary- opportunity time. Science and Environment fortnightly, *Down To Earth*. Jan 31. P. 50.

Yajiema., Mark Richards., Moustafa Ghanem., Yike Guo., John Hassard. 2008. Air pollution monitoring and mining based on sensor grid in London. *Sensors*, 8:3601-23.