Design and Implementation of Equipment for Air Quality Information Management System

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***Abstract*—Air pollution monitoring is considered as a very complex task but nevertheless it is very important. The environmental concerns have been growing along with the development of human race and their population distribution. Various factors contributing air pollution are industrial, commercial, domestic activities, and transportation. Statistics show that among these sources, motorised transportation is the highest contributing air pollution in recent past especially in urban areas. Therefore, assessing quality of the ambient air for breathing time to time is very important to control further damage. Currently, to access air quality related data is limited. To overcome this, authors have designed and implemented an Air Quality Monitoring Instrument (AQMI) using solid state gas sensors and GPS module and integrated with the information management system. The AQMI is used to collect the air quality data for the selected routes in Chennai city. The data collected in 2013 and 2017 are analyzed and generated as air quality information management system. The benefits of a fully integrated system for air quality data would be the easy view, sort and analyse the data to give them meaning and make them applicable to real life. Air health conscious people could also take advantage of this to navigate through pollution free areas. Patients with air pollution related health problems would find these reports valuable to determine the less polluted routes. In the future, with the developments of miniaturization of instruments, these instruments may be worn like wrist watch and will be known the ambient air quality in real time wherever people go.**

***Index Terms*—motorized vehicls, emissions, air pollution, health problems, gas sensors, real time mobile monitoring**

I. Introduction

Air pollution in urban areas is posing a great threat to urbanites all over the world. It is the 5th leading cause of deaths among top 10 killers across the world [1]. The various factors that contribute to air pollution are industrial, commercial and domestic activities. Industrial activities include manufacturing of chemicals, metallurgical and metal processes to make semi-finished and finished goods, electroplating, painting, *etc.* Commercial and domestic activities include motorised transportation, combustion of fuels for cooking and heating, burning of wastes on roadsides, construction activities, *etc.* Statistics shows that among these sources, motorised transportation is the one of the major contributors of air pollution, about 60 to 70 % in urban areas, in the recent past [2]. Further it may increase unless any major mitigation measures are planned and implemented. Therefore, assessing the quality of the atmospheric air we breathe from time to time is very important to control further damage.

Current pollution measurement methods use expensive equipment at fixed locations or dedicated mobile equipment laboratories. The analysis of samples in practice are Mass Spectroscopy (MS), Gas Chromatography (GC), Fourier Transform Infrared Instrument (FTII) method *etc.* provide accurate and selective gas reading, but cumbersome, expensive and time consuming. Due to these reasons researchers started designing cost effective embedded systems with readily available low cost solid state gas sensors having fast response and possibility of real time data transfer.

Solid state gas sensors are the type of gas sensors which cause change in electrical resistance by a loss or a gain of surface electrons as a result of adsorbed oxygen reacting with the target gas. Quantitative response is achieved as the magnitude of change in electrical resistance is a direct measure of the concentration of the target gas. In this study, readily available sensors in the market are used to measure air quality. Hence sensors are not developed specific to this study.

Manuscript received June 1, 2018; revised October 8, 2018.

doi: 10.12720/jait.9.4.117-122

It has been reported that the vehicular emissions contribute carbon monoxide, carbon dioxide and nitrogen oxides to the air pollution [3]. The major contribution to Chennai air pollution load is vehicular sector (71.28%) followed by industrial sector (19.70%) [4]. The objectives of this study are (i) To design and develop an AQMI using solid state gas sensors and GPS (ii) To analyse the air quality data in 2013 and 2017 in Chennai for selected four routes (iii) To display the measured air pollution levels at Chennai city in real time through a website (www.airpollutioninchennai.com) and (iii) To analyse the air pollutants levels and suggest mitigation measures.

II. Literature Review

Various attempts have been made to employ mobile monitoring systems using sensors in order to obtain *fine-grained* air quality data. In order to bridge the gap between the sampling phase and the analysis phase, researchers introduced monitoring approaches using commodity sensors, which can provide real time air pollutants' data. An air pollution monitoring study conducted on school bus at University of California along with National Resources Defence Council (NRDC) highlighted the health hazards posed to school children by their exposure to diesel pollutants.

The study emphasized the urgent need for mobile monitoring of air quality as the diesel exhaust is known for its carcinogenic character and a cause of respiratory illnesses [5]. Narasimha Murthy *et al.* have designed a wireless network consists of end devices with sensors, routers that propagate the network over long distances [6]. Their design is based on ARM7 processor with LPC2378 microcontroller and EZ430RF 2480 ZigBee module to process and communicate the data effectively with low power consumption.

A wireless sensor system for real-time monitoring of toxic environmental volatile organic compounds was developed by Tsow *et al.* [7]. This system was based on a smart sensor micro converter equipped with a network capable application processor that downloads the pollutants level to personal computer for further processing. Jung *et al.* have installed an air pollution geo-sensor network consisting of 24 sensors and 10 routers to monitor several air pollutants [8]. Raja Vara Prasad *et al.* have formed multi-hop mesh network with the array of pre-calibrated sensors interfacing with the wireless sensors motes and have been developed a light weight middleware and web based interface for online monitoring of the data in the form of charts from anywhere on internet [9].

III. Air Quality Monitoring Instrument (AQMI)

The proposed integrated equipment will increase effective way of data collection and processing and reduce operating costs. Air quality data will be more easily available and accessible by the public and the air quality community and the regulatory authorities. The amount of time spent in searching, manipulating and interpreting data will be greatly reduced. New data collection approach and architecture that incorporates a spatial data infrastructure are developed to enable access to the Chennai city air quality data. AQMI designed and implemented for mobile monitoring of air quality in real-time. It consists of a hardware unit that integrates a single-chip microcontroller (ARM7 processor – LPC2129 is TDMI-S CPU with real-time emulation and embedded trace support), air pollution sensors (CO_2, CO and NO) array, signal sensing conditioners and a GPS-module. Its output is connected to a high-end personal computer (PC) with GSM module which acts as internet connectivity.

The hardware unit gathers air pollutants' (CO_2, CO and NO) concentrations and packs them in a frame with the GPS physical location, time and date. This frame is subsequently uploaded to the GSM-Modem through RS232 interface and transmitted to the Central-Server via wireless network. Central-Server is interfaced to Google Maps to display the location of hardware unit. The basic building blocks of AQMI equipment are shown in Fig. 1 and Fig. 2.

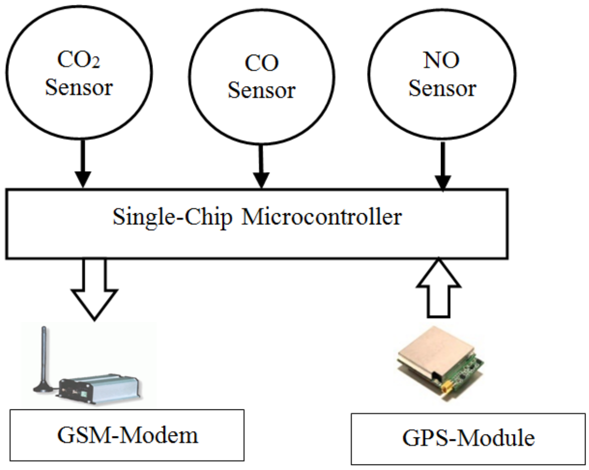

Figure 1. Basic building block diagram of data receiver (ARM-7 Module).

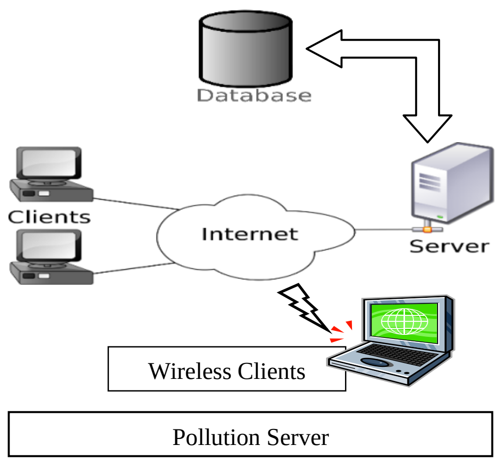

Figure 2. Basic building block diagram of data network system.

The list of sensors along with their features used in the AQMI is presented in Table I.

TABLE I. FEATURES OF THE SENSORS USED IN THE AQMI

Sensor	CO_2 (ppm)	CO (ppm)	NO (ppm)
Response time (T90) (s)	<120	<60	<45
Operating range (ppm)	350 – 30000	0 - 10000	0 – 20
Operating life (yrs)	>2	>2	>2
Diameter in mm	20	20	20
Sensitivity	44~72mV/ppm	1.2~2.4nA/ppm	400~480mV/ppb

The method of data collection from the initial stage to the final, are explained here:

(1) *Gas Acquisition.* In order to monitor the air quality in an area of interest, a user has to use our AQMI which measures the concentration in the air of some damaging pollutants, such as, CO_2, CO and NO for the selected interval of time.

(2) *Data Transfer.* After that the concentrations of the various pollutants have been collected through sensors, the obtained data are arranged in a packet and transmitted to the server, through the Internet, using GPS technology.

(3) *Air Quality Index Calculation.* Once the pollutionserver has received the gas concentrations from AQMI, it calculates the *Air Quality Index (AQI)* for that location. Air quality index values are typically grouped into ranges. Essentially, the server derives a number that indicates how good/bad the air quality is, so that increasing values correspond to higher pollution levels. Formulas for AQI calculation are defined by government agencies and vary from country to country. In India there are six AQI categories, namely Good, Satisfactory, Moderately polluted, Poor, Very Poor, and Severe.

(4) *Data sharing and Display.* Data obtained from AQMI are stored inside a database and are made accessible to the pollutioncommunity. A website www.airpollutioninchennai.com is designed and developed to display the pollutants' concentrations measured at different locations in real-time as shown in the Fig. 3. The AQMI measures concentrations of gases such as CO, CO_2 and NO and displays on the website in real time. The information displayed consists of hardware location with round red color pointer on Google map on right side. The table consists of pollutants' concentration with time at centre and the date above the table. On left side, the red, blue and black color lines are graphical representation of pollutants' concentration CO, CO_2 and NO respectively.

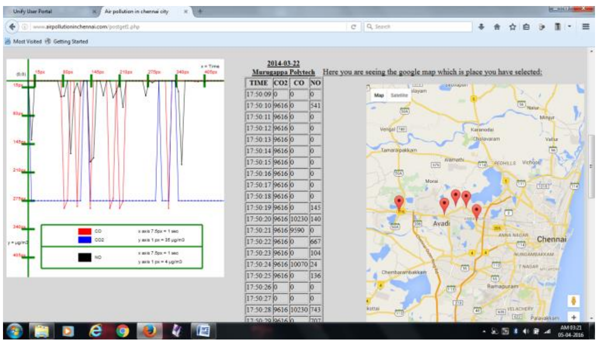

Figure 3. A sample image of the website.

IV. INFORMATION MANAGEMENT OF AIR QUALITY DATA USING AQMI

First requirement in air quality monitoring is the location of sampling sites, which must be representative of the area under study. The locations selected are based on the traffic volume and different roads so that the pollution levels are known for different areas. During monitoring of air quality the AQMI instrument's data receiver system is mounted on top of the car (about 1.5m height from the road surface) while the data network system is kept within the car for data collection and storage. Four routes are selected for monitoring within and around the Chennai city. Different routes covers different areas such as high and low traffic volumes, domestic, commercial and industrial areas. Routes selected and monitored are Avadi to Tambaram (Route1-R1), Neelankari to T. Nagar (Route2-R2), Avadi to Chennai central (Route3-R3) and Tonakela camp to Redhills bus-stand (Route4-R4).

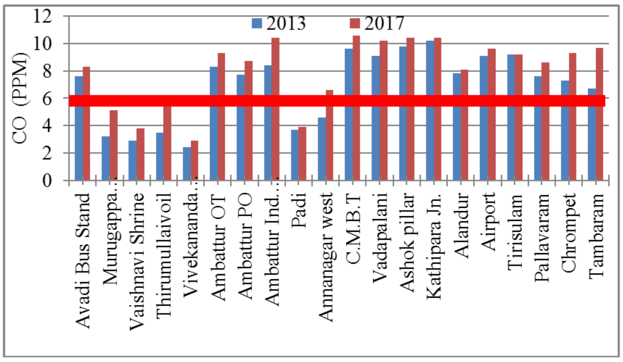

Figure 4. CO Concentrations at various locations on route 1 in 2013 and 2017.

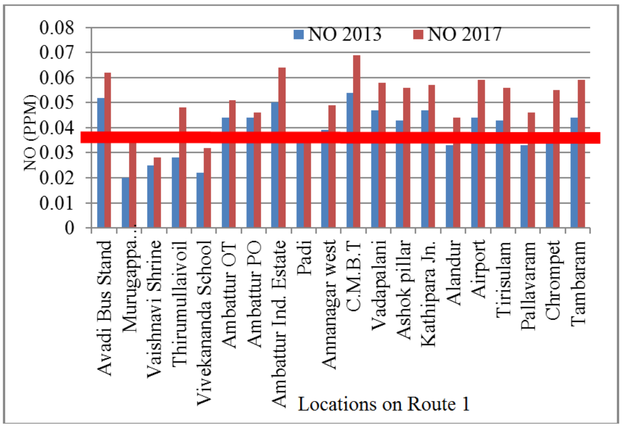

Figure 5. NO Concentrations at various locations on route 1 in 2013 and 2017.

As per the norms of Central Pollution Control Board (CPCB), the limits for pollution levels for CO and NO are $\leq$ 6 ppm and $\leq$ 0.035 ppm respectively. There are no specified limits for CO_2. The observed pollution levels of CO and NO are shown for route 1 in the Fig. 4 and Fig. 5 respectively. The red colored bar on CO and NO bar charts represents the permissible concentration levels as per the Ambient Air Quality Standards specified by the Central Pollution Control Board. From the overall study, it has been observed that in all routes except the few places, pollution levels increased at all places in 2017 when compared to 2013 observed noise levels. It can be mainly due to increase in motor vehicles and more traffic on roads. The motor vehicles population in Chennai as on 01-03-2013 were 38, 81, 850 and it has increased to near about 54, 44, 777 by March 2017. It clearly shows that the increase in pollution levels is due to increase in number of motorised vehicles that came to ply on the roads.

A. Analysis of Air Pollutants Monitored in Four Routes

Routes 1 and 4 together runs from South to North and Route 3 from West to East and Route 2 running through another important area on the sidelines of the coast are shown in Fig. 6. It was observed that in 2013, the pollution levels of CO at routes 1, 2 and 3, 60 to 75 % of locations have more than CPCB norms (6 ppm) except in the route 4. Route 4 covers sub-arterial roads (with more residential areas along the road) and a part of National Highway-5 (NH5) in the Chennai Metropolitan Area. It was found that interior roads are having the pollution levels within the norms and along NH5 exceeded. It is same case when the pollution levels were monitored in 2017 but increased concentrations except two at places in the route 1 namely Padi and Trisulum, two places in route 2 namely Gandhi Nagar and Anna University, one place in route 3 namely Vivekananda School and along route 4 more or less remained same at all locations. The Vardha Cyclone in December 2015 had uprooted many trees and also subsequent increase in motor vehicles population in Chennai caused increase in pollution.

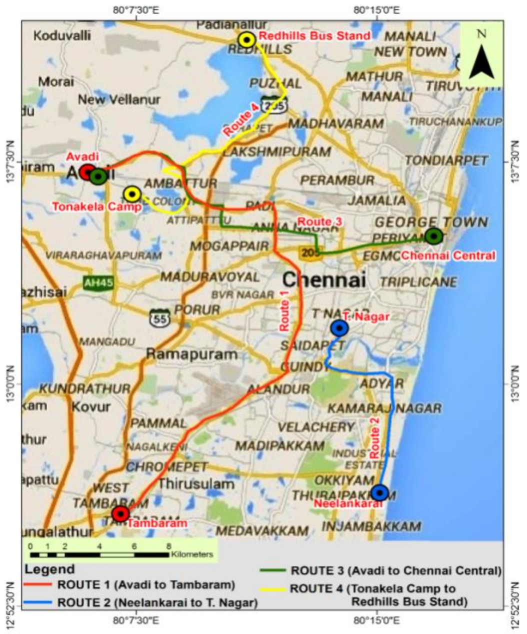

Figure 6. Four routes in which the pollution levels measured in Chennai city.

In 2013, the observed pollution levels of NO along the routes 1, 2 and 3 were exceeded at about 60 to 80% of locations except route 4 where only at 3 places on the National Highway (NH) exceeded the CPCB limits (0.035 ppm). In 2017, the monitored values shows substantial amount in increase of pollution levels on the routes 1, 2 and 3 except route 4. In the route 4 at four places exceeded the norms including the 3 places that of 2013 year and at all other places it remained within the limits but increased due to increase in vehicles population. The pollution levels obtained by using AQMI are robust in obtaining the pollutants' concentrations which can be made available in real time and can be used for assessing the air quality.

B. Report Generation of Air Pollutants Monitored in Four Routes

Managing the data collected is just as important as collecting the data. The amount of data collected will continue to grow based on the needs of the data users. With electronic records and electronic media, this information can be stored and managed with less use of space than with the conventional paper records. All information collected in any ambient air monitoring program should be organized in a logical and systematic manner. There is no one best way to organize a system.

All concentration data should be assessed in order to evaluate the attainment of the data quality objectives (DQOs) or the monitoring objectives. These assessments can be documented using the following types of reports:

- **Data quality assessment (DQA)** is the scientific and statistical evaluation to determine if data are of the right type, quality, and quantity to support their intended use (DQOs). QA/QC data can be statistically assessed at various levels of aggregation to determine whether the DQOs have been attained.
- **Data Quality Indicator Reports** have been programmed to assess data quality in AQMI. In particular, it provides a visual display of data quality that can help identify sites that may be in need of corrective action.
- **QA Reports** provide an evaluation of QA/QC data for a given time period to determine whether the data quality objectives are met.
- **Audit Report**s provide the formal documentation of internal and external audits including any findings that require corrective action.

C. Suggestions for Mitigation Measures

Our new environments should be 'future proofed' to cope with the demands placed upon the future population; for example innovative schemes to maintain air quality providing traffic free zones, designing pedestrian friendly streets, making footpaths usable always (i.e. removal of obstacles immediately, if placed across footpaths by defaulters) which will ensure safety as well to both pedestrians and commuters on vehicles. Design of streets might include special provision for non-motorised transport for example bicycles, tricycles, *etc.* In general, civic bodies in all towns and cities should adopt design of environmental friendly streets and sustainable mobility.

In Chennai, currently, many main roads lack proper footpaths, a situation that becomes worse with the monsoon. If footpaths are maintained well then many people even like to walk for small distances rather than using motor vehicles. To protect air quality, more plants might be planted, and soil protection measures are to be taken to preserve this vital resource for proper growth of plants. Planning and policy might also take account of people's desire for self-sufficiency and provenance which will indirectly helps in maintaining of good quality of air. Contemporary construction and then deconstruction of urban fabric and consumer products will also be key to resource re-use and waste minimization to avoid an urban environmental pollution burden in the future greater than that which we are already dealing with.

Size and population of cities are ever growing process; to cope of with the situation, each city needs a number of AQMI devices to cover the air quality monitoring for different areas. It is also to be noted that the same area is required to be monitored in different timings of the day as the air quality changes from time to time due to change in traffic volume. Number of devices required may be decided based on to what extent each device is able to be utilized effectively.

V. Conclusions

This paper presents fine-grained real time mobile monitoring instrument deployable on public transportation infrastructure and personal vehicles. The air pollution level is increased due to the Vardha cyclone which uprooted many trees in the city in 2016 and also due to simultaneous growth in motor vehicles population. 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 be done to commercialize the instrument. It is necessary to increase the number of plants within and around the city to protect the environment.

The air quality data obtained using such sensing instruments could serve various applications. Individuals using such system may become more knowledgeable about the extent of air pollution and shall be motivated to follow the better driving patterns. It includes not allowing vehicles to be idle for long periods, driving at a speed that generates less air pollution, driving through less polluted areas, keeping vehicles in good condition and following proper maintenance procedures. Health conscious people could also take advantage of this to navigate through pollution free areas. Patients with air pollution related health problems would find data valuable to determine the less polluted routes. Apart from these applications, this data could be used for policy making on prevention and control of air pollution through regulatory and legislative means. For example, public health officers and policy makers could use the data to predict potential health impacts across various areas of city to make decisions on new bus routes formation, sanctions for establishment of new schools and colleges *etc.*

References

[1] Air pollution killing 620,000 Indians every year: Global Burden of Disease report. [Online]. Available: http://www.downtoearth.org.in/content/air-pollution-killing-620000-indians-every-year-global-burden-disease-report

[2] S. K. Singh, "Review of urban transportation in India," *J. Public Transportation*, vol. 8, no. 1, pp. 79-97, 2005.

[3] Automobile Emissions: An Overview. United States Environmental Protection Agency – Office of Mobile Sources. [Online]. Available: http://www.epa.gov/otaq/consumer/05-autos.pdf

[4] *Development Plan for Chennai Metropolitan Area*, Chapter VI – Environment and Disaster Management, CMDA special publication, The Chennai Metropolitan Development Authority, Chennai, 2006.

[5] R. Honicky, E. A. Brewer, E. Paulos, and R. White, "N-SMARTS: networked suite of mobile atmospheric real-time sensors," in *Proc. Second ACM SIGCOMM Workshop on Networked Systems for Developing Regions*, New York, NY, USA, 2008, pp. 25-30.

[6] Y. N. Murthy, V. Sukanya, and C. Saritha, "Design and development of ZigBee based wireless sensor network for monitoring air pollutants," *International Journal of Scientific & Engineering Research*, vol. 4, no. 3, pp. 1-5, 2013.

[7] F. Tsow, *et al.*, "A wearable and wireless sensor system for real-time monitoring of toxic environmental volatile organic compounds," *IEEE Sensors J.*, vol. 9, pp. 1734-1740, 2009.

[8] Y. J. Jung, Y. K. Lee, D. G. Lee, K. H. Ryu, and S. Nittel, "Air pollution monitoring system based on geosensor network," *IEEE International Geoscience Remote Sensing Symposium*, vol. 3, pp. 1370-1373, 2008.

[9] R. V. Prasad, *et al.*, "Real time wireless air pollution monitoring system," *ICTACT Journal on Communication Technology*, vol. 2, no. 2, pp. 370-375, 2011.

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