International journal of application or innovation in engineering and management

ijaiem.com/May 2018 Volume 7/Issue 1/Article No-1/11-21
ISSN: 2319-4847

AIR POLLUTION MONITORING SYSTEM THAT WORKS IN REAL TIME

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Article Info

Received: 17-02-2018 ***Revised: 21 -03-2018*** ***Accepted: 06-04-2018*** ***Published:15/05/2018***

Abstract:
Polluted air has a big effect on the amount of different substances in the atmosphere, which causes things like acid rain and global warming. An air pollution tracking system is very important to keep nature from getting out of balance in these ways. In this study, we try to make a real-time wireless air pollution tracking system, which is an effective way to keep an eye on pollution using wireless sensor networks (WSN). Discrete gas sensors that are sold in stores can measure the concentration of gases like CO2, NO2, CO, and O2. These sensors are adjusted using the right technologies. The pre-calibrated gas sensors are then put together with the wireless sensor motes so they can be used in the field on campus and in the city of Hyderabad. A multi-hop data gathering method is used for this. A small piece of software and a web interface were made so that anyone on the internet could see live pollution data from the test beds in the form of numbers and charts. It was possible to use data fusion methods to look at the data after measuring other things like temperature and humidity as well as gas amounts. The created wireless air pollution tracking system has been tested in a variety of physical settings and has proven to be a reliable source of real-time fine-grain pollution data.

Keywords:

Wireless Sensor Networks (WSN), Gas Sensor Calibration, LightWeight Middleware, Multihop Data Aggregation, Web Interface.

1. INTRODUCTION

Because of fast economic growth, air pollution showed up in many parts of the world. Transport by road is also a major source of air pollution, which in turn contributes to climate change, which has dangerous effects on both the global and local levels [1]. How polluting materials are made and moved is affected by both where their sources are located and how the weather is moving. It is sometimes possible to see pollutant clouds moving with the wind [2]. We need more information on how fine-grain pollution spread and change over time in Fourier transform infrared (FTIR) devices, gas chromatographs, and mass spectrometers are some of the tools that can be used to track air pollution. These devices give readings of gases that are pretty exact and selective. Their high cost, big size, and high upkeep costs, on the other hand, made them unsuitable for large-scale tracking [3]. A gas monitor that is small, strong, can be used in many ways, and doesn't cost much could also work well [4]. Electricity, infrared light, catalytic beads, photo ionization, and solid-state are some of the methods used to measure gases [3]. Smart transducer interface module (STIM) with semiconductor gas monitors, which follow the 1451.2 standard, are a big part of the current monitoring system. It was found that STIM was a good tracking system, but it needed a lot of power and couldn't be expanded for big deployments. Another big sensor network used for tracking and making predictions is the Environment Observation and Forecasting System (EOFS) [6]. However, the system is too big and costs too much to set up at first. Due to its high cost, the air pollution tracking system suggested in [7] that is built on a geosensor network with control action and adaptable sample rates can't be widely used either. The objective of this work is to come up with cost effective, reliable, scalable and accurate real-time air pollution monitoring system with wireless sensor networks. Commercially available electrochemical and resistive heating type sensors were used to sense the gases like O_2, CO_2, CO and NO_2. Appropriate calibration technologies were developed to calibrate these sensors, which are then interfaced to wireless sensor motes. Zigbee based wireless sensor networks with multihop data aggregation algorithm were implemented to [13] extend the range of monitoring area. The calibration technology for the gas sensor, system architecture of real time wireless pollution monitoring system, field deployment and experimentation with varying physical conditions and various challenges faced during the design, development and deployment of the system are discussed in the following sections.

2. CALIBRATION OF GAS SENSORS

International journal of application or innovation in engineering and management
ijaiem.com/May 2018 Volume 7/Issue 1/Article No-1/11-21
ISSN: 2319-4847

to stabilise and amplify the measured signal from the sensors during the calibration process. The sensors along with the conditioning circuit are placed in the chamber and readings are noted down for regular PPMs of the gas. Each sensor produces a voltage value corresponding to the input concentration of gas. These observed values are plotted and a characteristic equationis formulated to map voltage signals into corresponding concentrations in PPM. The calibration process for O_2 and CO_2 is discussed in detail in the following sections.

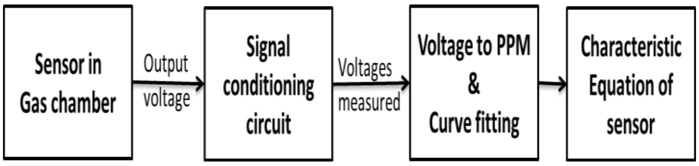

Fig.1. Various steps in the gas sensor calibration process

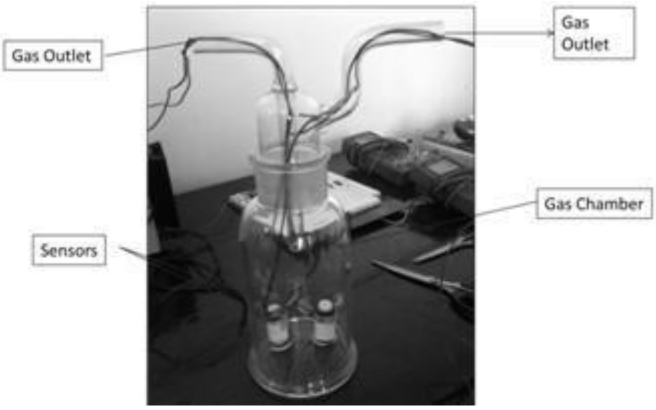

Fig.2. Gas chamber used for calibration process

2.1 CALIBRATION OF CARBON DIOXIDE

Figaro's TGS4161 (Fig.3) is a solid electrolyte (a type of solid state sensor) CO_2 sensor with detection range of 350 to 5,000ppm [8]. The sensitive element of the sensor consists of a solid electrolyte formed between two electrodes, together with a printed heater substrate. CO_2 concentration is measured by monitoring the change in electromotive force (EMF) generated between the two electrodes. This type of solid electrolyte sensor features selectivity towards target gas, small in size, low cost and has long life expectancy (>10 years)[9][15].

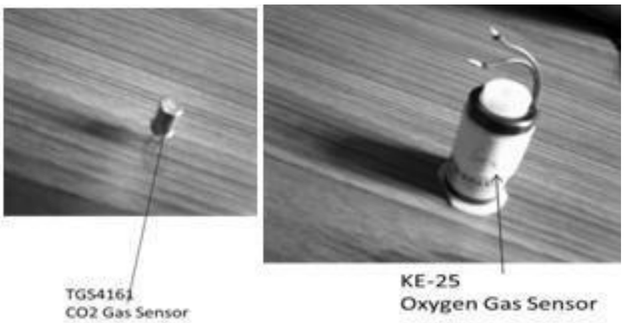

Fig.3. CO_2 and O_2 gas sensors

Calibration of the TSG4161 sensor was performed in a laboratory environment with a sealed gas chamber shown in Fig.2. The sensors were placed in the container for calibration.

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ijaiem.com/May 2018 Volume 7/Issue 1/Article No-1/11-21
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The test gas is a composition of 10,000ppm Carbon dioxide gas with balanced N2 and synthesized air with 10% Hydrogen. The sensors are calibration with CO2 concentration between 350ppm(atmospheric concentration) and 2000ppm. This type of resistivesensors is sensitive to temperature changes and room temperature of the calibration environment was maintained at around 25 degree. The flow rate was maintained at 200 ml/minin closed chamber during experiment. The gas concentration wascrosschecked with gas analyser. The gas analyser reported a good match for values between 350ppm to 1200pm and above that a 2-5% deviation of gas concentration was observed. Five sensors of the same types were calibrated. Before testing each concentration, the sensor has been exposed to atmospheric CO_2 concentration 350ppm for 10 minutes. After each tested the gas concentration will return to 350ppm before the next test starts.

The measured sensor signal strength was low, typically of the order of 220mV for the atmospheric concentration of 350ppm for CO_2 sensor and was highly unstable. To stabilize and amplify the measured signal, sensor signal conditioning circuits with amplifier and filter were used during the calibrationprocess Fig.4.

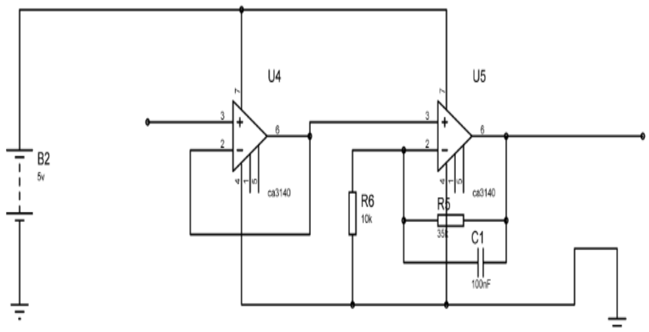

Fig.4. Signal conditioning circuit for CO2 sensor – TGS 4161

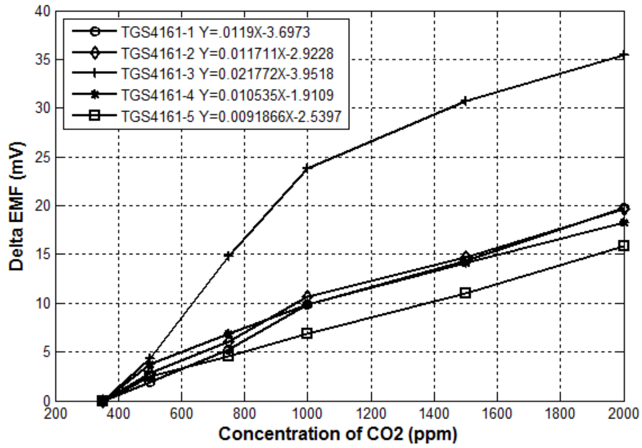

Fig.5. Calibration result for Figaro TSG4161 CO_2 sensors Fig.5. shows the calibration results of the five different TSG4161 CO2 sensors. It was observed that the output of TGS4161 is linear in semi-log scale up to 1000ppm and afterthat it slightly deviates and is approximately linear. By curve fitting, the equations for each of the sensors are arrived at which is given in Fig.5.

Calibration equation for CO2 sensor is

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*For Sensor1, y = p1*x + p2,where,*

y is the measured voltage valuex is the concentration of CO_2

Coefficients: p1 = 0.011992, p2 = -3.6973

For the rest of the sensors, the equation is given in Fig.5.

2.2 CALIBRATION OF OXYGEN SENSORS

Figaro's Oxygen Sensor KE-25 (Fig.3) is a unique galvanic cell type oxygen sensor, which was developed in Japan in 1985. It provides a linear output voltage signal relative to percentageof oxygen present in a particular atmosphere. The sensor features long life expectancy, excellent chemical durability, and it is not influenced by CO_2, CO, H_2S, NO_x, H_2 [10]. Moreover, itoperates at normal ambient temperature and requires no warm uptime making, it ideal for oxygen monitoring for portable applications.

The setup for the calibration of KE-25 was the same as the calibration of CO_2 sensors, except for the oxygen used wasgenerated by an oxygen generator and is diluted with synthetic air. Two MFCs were used and the K-factor for Oxygen gas with H_2S calibrated was 1.24. K-factor for synthetic gas with Hydrogen calibrated was 1.48. The calibration was performed at room temperature of around 15°C and the flow rate was maintained at 300 ml/min in sealed gas chamber. The sensor is tested with different concentrations at the interval of 5% from 15% to 50%.

We have observed that the effect of temperature and humidity has negligible effect on the sensor output. KE-25 gives a very stable output voltage with amplitude between 11-14 mVin ambient air. We have employed sensor conditioning circuit with high impedance stage follow by an amplification gain of 100 in the calibration process Fig.6.

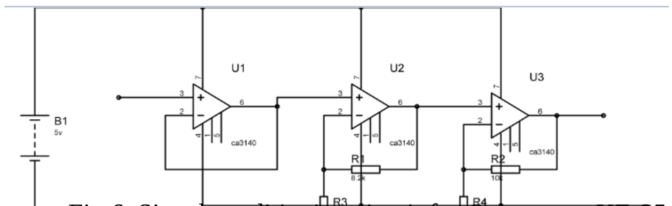

Fig.6. Signal conditioning circuit for O_2 sensor – KE-25 Fig.7 shows the calibration result of the three different KE-25 O_2 sensors. It is observed that the output of the oxygen sensor(KE-25) is linear for all range of oxygen concentration. The relation of the output voltage and gas concentration can be represented by

$O_2 = (V_a - V_0)/(V_{100} - V_0)$ *(1)*

where,

O_2 *= measured concentration of* O_2 *gas*

Va = Output Voltage of the sensor at tested concentration.

V_0 *= Output Voltage of the Sensor at 0% oxygen concentration*V_{100}*= Voltage of the Sensor at 100% oxygen concentration*

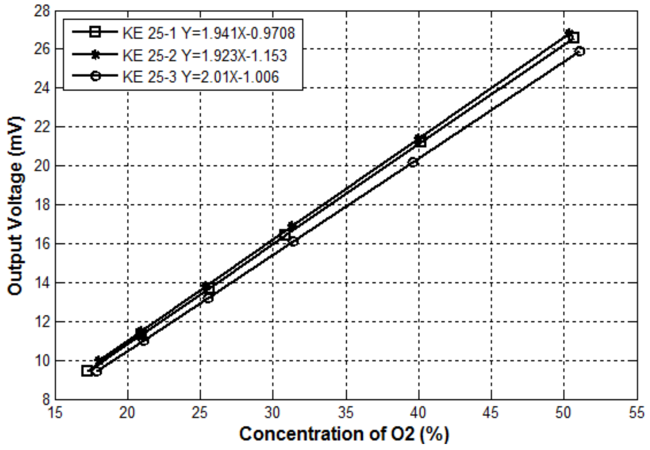

Fig.7. Calibration Result for Oxygen sensor KE-25

The calibrated equation for each of the sensor obtained after the experiment is given in Fig.7. Having calibrated the sensors, the system architecture to which these sensors are interfaced is discussed in the following section.

3. SYSTEM ARCHITECTURE OF REAL TIME WIRELESS AIR POLLUTION MONITORING SYSTEM

The real time wireless air pollution monitoring system was designed and developed to obtain the fine-grain pollution data ofthe gases like CO_2, O_2, NO_2, CO along with other parameterslike temperature, humidity, and pressure. The architecture of the monitoring system is shown in Fig.9. The design and development of the pollution monitoring system constitutes the following stages.

1. Calibration of gas Sensors (Discussed in section II)
2. Configuring Wireless sensor nodes for air pollutionmonitoring
3. Development of middleware
4. Field deployment.

3.1. CONFIGURING WIRELESS SENSOR NODES FOR REAL TIME AIR POLLUTION MONITORING

The pre-calibrated commercially available gas sensors are interfaced to wireless sensor motes/modules through the gas sensor board, which are programmed for air pollution monitoring application. Libelium WASP motes are used as the basic wireless communication module, which comprises of the processing unit and the communication unit Fig.8. ADC (analog to digital converter) ports of the wireless nodes are programmed to periodically sample the various gas sensors interfaced to the sensor board on a rotational basis. The collected samples are packetized and sent to base station [12] [16] at regular intervals from each of the sensor node, which forms the mesh network (Fig.9). To increase the monitoring range, multi hop data aggregation algorithm [13] was implemented. To configure RF Xbee module, gain of signal conditioning and other modules on the WASP system refer [11]. The real time pollution monitoring test bed was developed and deployed with five node network.

Fig.8. Libelium WASP mote and the sensor board with differentgas sensors

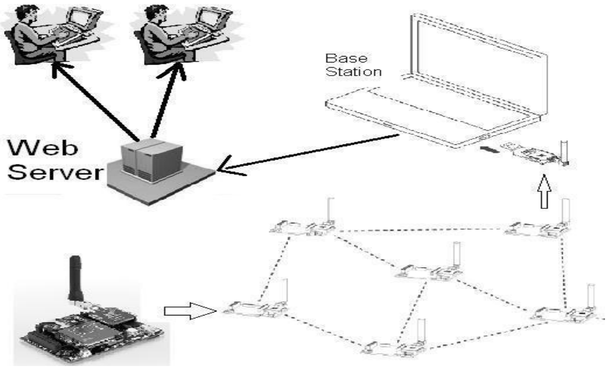

Fig.9. Multihop mesh network system architecture for the realtime wireless pollution monitoring system.

3.2 LIGHT WEIGHT MIDDLEWARE AND WEB INTERFACE

Base station or the sink node receives data at regular intervals of time from the deployed network. Light weight middleware is developed for effective storage and retrieval of data. An application to read data from serial port and convert to appropriate format is developed using visual studio. Parsed data is logged in to the database in the form of tables along with the time stamp of each packet. A web based graphical user interface (GUI) is developed to view the live data in the form numbers and charts, which is made accessible from anywhere on internet.

Data is sent to the base station through multihop network. Data repository with effective, efficient and secured data transactions is required. This repository should have the facility of web based service requests as well as sms based mobileservices for effective data access. Data from repository should also be targeted for sensor web enablement may be a ―**sensor wiki**‖ for sensor information with geospatial information.Standardization in terms of gas sensor systems is to be developed like TML [17] protocol for exchanging live streaming or archived data to (i.e. control data) and/or sensordata from any sensor system. Data repository with interoperability (technologies like WIFI, Bluetooth etc..) is also incorporated.

3.3. PILOT DEPLOYMENT OF THE REAL TIME AIR POLLUTION MONITORING SYSTEM AND OBSERVATIONS:

Pilot deployment of the wireless air pollution monitoringsystem was carried out at two different places, namely IIT Hyderabad campus and at high trafficking area of Hyderabadcity – Kukatpally. The objective of the deployment is to collect the fine grain pollutant data in these areas. The five node

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ijaiem.com/May 2018 Volume 7/Issue 1/Article No-1/11-21
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pollution monitoring test bed deployed at IITH campus which is far away (30 km) from the urban polluted area is shown in Fig.10. Nodes were placed at different locations of the campus to monitor the gases like CO_2, O_2, CO and NO_2. Along with the gases concentration parameters like temperature, humidity, and pressure were also monitored at these locations. Real time plots of these gases along with other parameters are plotted with the middleware and the GUI. At IITH campus most of the times, the observed data from all of the motes seems to reflect normal atmospheric concentration of the gases, which is for CO_2 – 350 ppm, O_2 – 21%, NO_2 – 0.7 ppm and CO-0.1 ppm. Experiments were performed by exposing some of the sensor nodes in the network to different physical conditions. Accordingly, one of thesensor nodes (mote1) was placed near the exhaust of the motor bike. The collected data from this node shows CO_2 concentrationof 900 to 1000 PPM with variation in acceleration of bike. It's also been observed that when the motor bike is switched off CO_2concentration come back to its normal atmospheric level of 350 to 380 PPM after some time. Other important observations are O_2 concentration is decreasing along with temperature and humidity variations Fig.11. One more experimentation was carried out were number of people near one of the motes was increased and the CO_2 concentration was found to increase as shown in Fig.12.

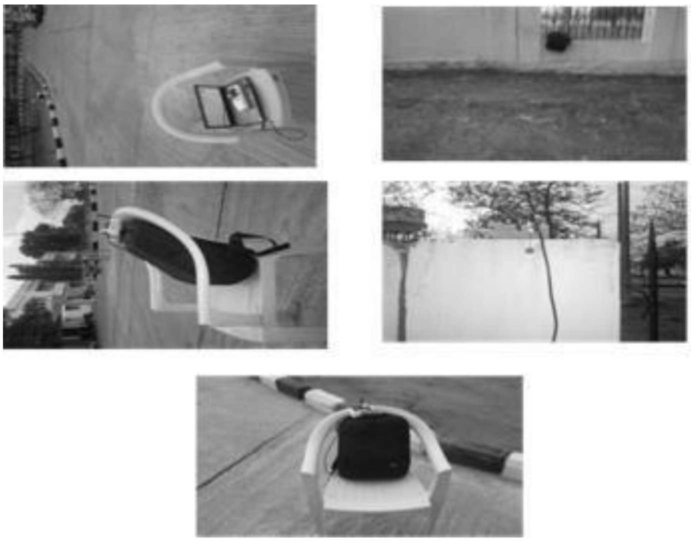

Fig.10. Wireless air pollution monitoring system deployed atIITH campus

Data collected from the next deployment at Kukatpally which is highly dense traffic area is shown in Fig.13.The CO_2 levels are almost at 1600-1800 PPM, we observe minor changes in NO_2 concentrations but are under safety limits. Oxygen levels are not very much varying except 0.1 to 0.2 % variations. Temperature was observed to be low and humidity was slightly higher. Level of pollutant was significantly high at Kukatpally ason the day of measurement there was rain.

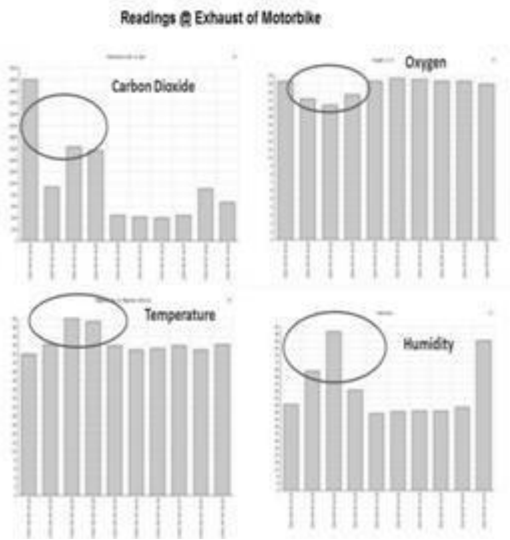

Fig.11. Gas concentration for mote-1 near the exhaust ofmotorbike

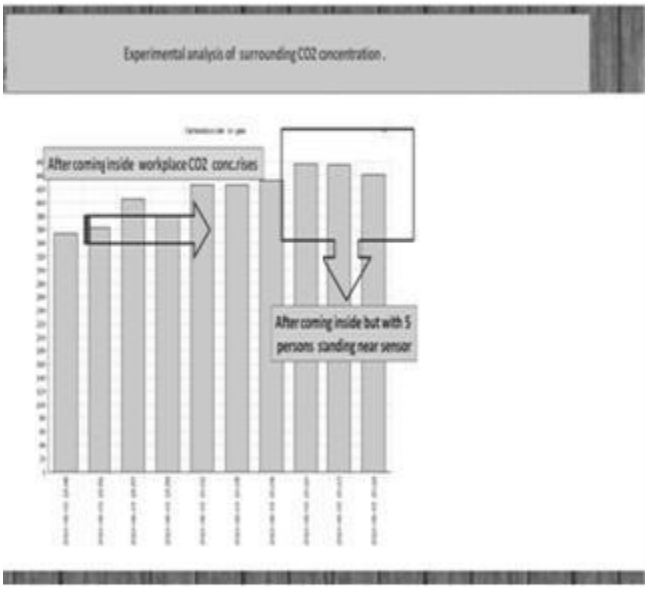

Fig.12. CO2 gas concentration for a mote surrounded by morenumber of people

3.4. ISSUES FACED DURING THE DESIGN ANDDEVELOPMENT OF THE SYSTEM

Air pollution sensors like CO_2, CO and NO_2 are resistive heating based sensors. They consume a lot of energy from the battery of wireless nodes which is detrimental to network life time. Chemical /MOSFET sensors need very less power but the cost is too high. The effect of temperature and humidity on resistive type gas sensors is to be considered for accurate readings. Calibration at periodic intervals is necessary but it is difficult to do for large no of sensors in field. Life of the sensors is very short (typically 6 to 9 months)[14]. Also the costs of Libelium motes were too high. In the next phase of the project, we plan to design and develop cost effective architectures for pollution monitoring systems. Energy of the wireless sensornodes should be utilized optimally. The sensed data from every node is sent at regular intervals of time. Data compression and data modeling algorithms helps in saving the energy of node by reducing the redundant data. Data should have geospatial information for better visualization or analysis of data. Sensor nodes should have the capability of estimation, quantification of the data. Sleep modes also to be included considering the statistics of the data received.

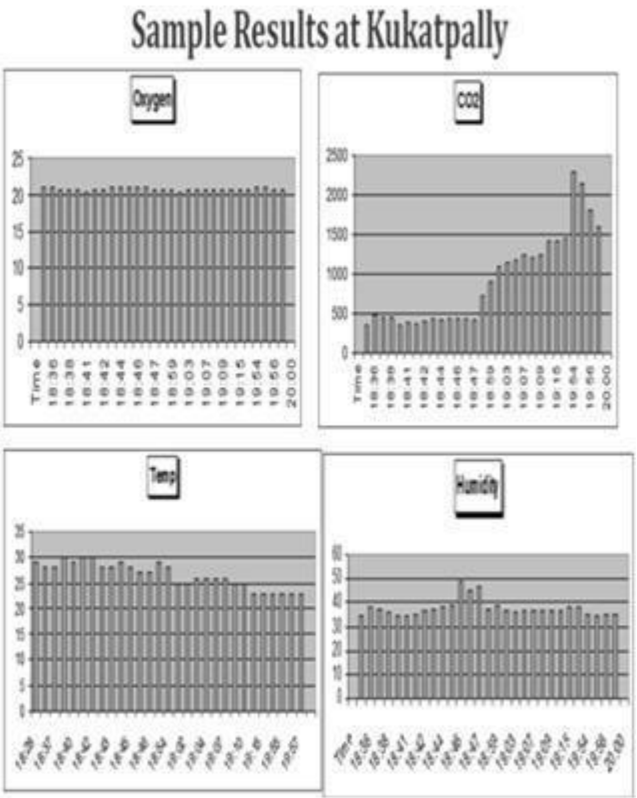

Fig.13. Data collected at Kukatpally using wireless pollutionmonitoring system

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ijaiem.com/May 2018 Volume 7/Issue 1/Article No-1/11-21
ISSN: 2319-4847

4. CONCLUSIONS

The importance of real-time wireless air pollution monitoringsystem is investigated considering the vital technical and economic issues for vast area deployment. Commerciallyavailable gas sensors were calibrated using the appropriate calibration technologies. These pre-calibrated sensors are then interfaced with the wireless sensor motes forming multi hop mesh network. A light weight middleware and web based interface were developed for online monitoring of the data in theform of charts from anywhere on internet. Pilot deployment of the system was carried out at the campus and at the Hyderabad city. Experimentation carried out using the developed wireless air pollution monitoring system under different physical conditions show that the system collects reliable source of real time fine-grain pollution data.

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The address is http://www.opengeospatial.org/standards/html.