System Engineering and Deployment of Envirobat

An Urban Air Pollution Monitoring Device

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Abstract— **We report on a cost effective, portable urban air pollution monitoring device, Envirobat, based on commercially available gas sensors. In order to carry out air pollution monitoring over an extensively large area, the device integrates inexpensive solid state sensors, along with GSM Module which transmits measured data at multiple ground sites to a centralized server through GPRS. This device facilitates rapid dissemination of information on pollution levels at multiple ground sites simultaneously. The device has the capability to sense location, atmospheric pressure, temperature, humidity, CO_2, CO, SO_2, NO_2, and O_3. The device is validated through calibration and deployment for indoor and outdoor sensing applications.**

Keywords-solid state gas sensors; air pollution monitoring device; wireless communication

I. INTRODUCTION

Air pollution has become a serious problem in densely populated and industrialized cities. In India, the problem is compounded by the increasing number of pollution sources like number of motorized vehicles and various process industries. Economic growth and industrialization are proceeding at rapid pace in the most of the cities, accompanied by increasing emissions of air polluting gases. Though the different types and quantities of air polluting sources have increased noticeably, the development of an appropriate method for monitoring and mitigating the pollution causing sources has not followed at the same rate. Environmental impacts of air pollutants have wider implications on public health and vegetation wealth [1] [2].

To prevent or minimize the damage caused by atmospheric pollution, suitable monitoring systems are urgently needed that can rapidly and reliably detect and quantify polluting sources. It would be ideal if we can deploy them at every traffic intersection in a city like Bangalore. This data will help regulating authorities to prevent further deterioration of the current air pollution levels. The current air pollution monitoring systems, used by pollution boards are very expensive and bulky and hence not scalable. Envirobat is developed specifically to address this issue, to design a low cost hand held device that can be mounted at multiple locations in an area to monitor air pollution at regular intervals of time. Envirobat is improved version of Enviromote which was developed during the initial stages of this activity [3].

Section II presents details on system engineering issues. The calibration methodology is detailed in Section III. The case studies for indoor and outdoor monitoring are presented in Section IV. Section V elaborates the software and GUI developed on the server side, to handle the sensor data.

II. SYSTEM ENGINEERING

A. Conceptual Design

Envirobat comprises of four different electronic modules: a. Sensor module b. Controller module c. Communication module (GSM / GPRS) and d. Memory interface module. The fig.1 below shows the block diagram of Envirobat.

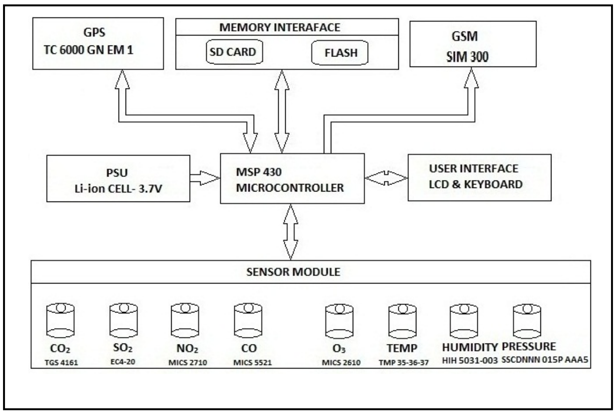

Fig.1. System Block diagram of the Envirobat

The heart of the device is the controller module which controls all the peripherals embedded in Envirobat. Sensor module is designed with atmospheric pressure, temperature, humidity, CO_2, CO, SO_2, NO_2, and O_3 sensors. Communication module is used to enable the wireless communication between Envirobat and the centralized server. It consists of GSM/GPRS modules. Memory interface module has the SD card interface and Flash memory to save collected gas sensor data.

B. ***Hardware Implementation***

Microcontroller: The controller board is based on TI's MSP430F5435A microcontroller. It controls timings for switching on/off of all sensors used in the device, processes the sensor output data and sends the sensor data to a server through a communication module (GSM). The board consists of the µController, power management unit, sensor signal conditioning circuitry and provision for connecting sensor and communication boards. Fig.2a given below shows the Microcontroller board design implemented on a PCB.

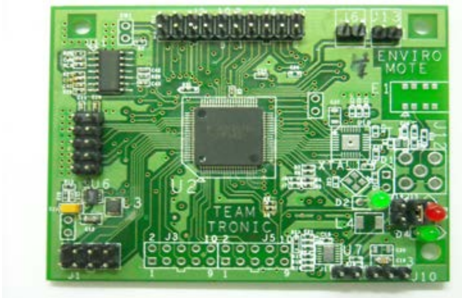

Fig.2a. Microcontroller Board

Communication module (GSM Board): Communication between Envirobat and Server is done through a Sagem Hilo GSM module. This design is implemented on a two layered PCB. Current consumption in Off mode is 35 µA while in Communication mode power consumption (at P_{max}) is 220 mA.

Fig.2b. communication module Board

Sensor module: Sensor module consist of pressure, temperature, humidity, CO_2, CO, SO_2, NO_2, and O_3 sensors. List of sensors and their details are listed in table 1. Figure 2c shows the sensor board module with mounted sensors and complete hardware assembly of Envirobat.

Fig.2c. Photograph of Sensor module and integrated board

Fig.2d. Photograph of Envirobat packaged in its mechanical enclosure

Table 1. List of Sensors used in Envirobat

Sensor	CO2	CO	NO2	SO2	O3	Temp	RH
Type	Metal Oxide	Metal Oxide	Metal Oxide	Electro chemical	Metal Oxide	-	-
Make	Figaro TGS4161	E2V MiCS-5521	E2V MiCS-2710	E2V EC4-20-SO2	E2V MICS-2610	National Semi LM35	Honeywell HIH-5031
Range	350-10000 ppm	1 - 1000 ppm	0.05 – 5 ppm	0 – 20 ppm	10 - 1000 ppb	-55^0C - 150^0C	0% - 100% RH

All the above hardware modules along with memory module are integerated to make complete hardware assembly of Envirobat. Figure 2d shows complete working prototype of Envirobat in its Mechanical Enclosure.

III. CALIBRATION OF SENSORS

Calibration of the gas sensors is one of the prime challenges during the development phase. The sensor calibration was carried out with dedicated gas sensors calibration setup. Although calibration of all the sensors is being done, the discussion here is limited only to the calibration of CO_2, temperature and humidity sensors.

A. *Gas Sensor Calibration Setup*

The main parts of gas sensor calibration setup are two MFC (Mass Flow Controller) along with a MFC selector, Mixing chamber and a Test chamber. The MFC selector helps in selecting MFC of synthetic air and target gas. MFC is used to control the flow of gas. Synthetic air is clean air with appropriate percentage of O_2 and N_2. For the calibration of CO_2 gas sensor, the test gas used is diluted CO_2 with 99.999% purity N_2. The test gas and synthetic air is mixed at an air tight container with inlet and outlet connections (test chamber). The gas sensor assembly is placed inside this chamber for calibration. Figure 3 and 4 show the Calibration setup schematic diagram and actual picture of gas sensor calibration setup respectively. For Temperature and Humidity calibration, an environment chamber with controlled temperature and humidity was used (VOTSCH VCL 7003).

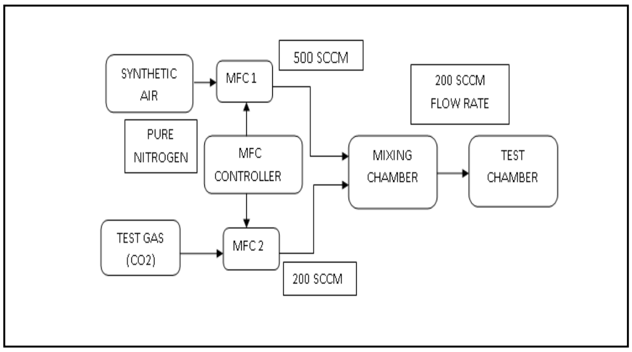

Fig.3. Schematic diagram of the Gas Sensor Calibration setup

Fig.4. Gas Sensor Calibration Setup and inner Arrangement of the chamber

B. *Calibration Methodology*

General procedure followed for calibrating a gas sensor:

- Place the sensor under test in a closed chamber which will be filled by the gas to be detected.
- Set the concentration of the gas to a known value and fill the closed chamber with the gas.
- Record the output of the sensor continuously for "sometime" (depends on the flow rate of the gas and the chamber size) for uniform distribution of the gas in the chamber.
- Repeat the procedure for a different concentration of the gas.
- Plot the output of the sensor versus gas concentration.
- Obtain the relationship between sensor output and gas concentration.
- Compare it with the sensor's datasheet relation and obtain the offset between the datasheet's values and practical values.
- The gas concentration level is calculated from the measured EMF values at sensor electrodes for CO_2 sensor. The actual EMF value decreases with increasing concentration of CO_2.

$$\Delta EMF = EMF\ (R) - EMF\ (G) \qquad (1)$$

where, ΔEMF is the difference between EMF values (mV). *EMF(G)* is the EMF value measured at unknown gas concentration and *EMF(R)* is the reference EMF when synthetic air with 350ppm of CO_2 is introduced. As per the data sheet

$$C=\Delta EMF*33.3+350 \qquad (2)$$

C refers to concentration of CO_2 in ppm. The constant *33.3* is obtained from sensitivity curve given in sensor datasheet. This parameter implies that for every 1mV change, concentration changes by 33ppm. ΔEMF is obtained from (1). The value of *350* refers to the ppm base value that is obtained from measurement with 350ppm CO_2 in synthetic air ($\Delta EMF=0$). Based on the actual experiments, the shift in the base value is observed to be between 5 to 7 %.

- The temperature sensor used in the Envirobat is TMP35.
- From the datasheet, the sensor gives an output of 500 mV at 0 ^{0}C. The output rises by 10 mV for every 1 ^{0}C.
- The humidity sensor used in the Envirobat is HIH 5031-003.
- The humidity level is calculated from the measured voltage values from the sensor.
- To calculate Humidity we use the following formulae

$$V_{out} = (V_{supply}) * (0.00636*(sensor\ RH) + 0.1515) \qquad (3)$$

$V_{out,}$ refers to output voltage from sensor. V_{supply} refers to the supply voltage in the range from 2.7 Volts to 5.5 Volts. S*ensor RH* refes to relative humidity of the sensor obtained from (3). *0.00636* and *0.1515* are the constants given by sensor manufacturer .

- True Relative Humidity is a function of temperature and is calculated as

$$True\ RH = (Sensor\ RH)/(1.0546- 0.00216T) \qquad (4)$$

True RH, refers to True Relative Humidity. *T* refers to temperature in ^{0}C. The constants *1.0546 and 0.00216* are given by the sensor manufacturer. These values are corrected as required, based on calibration performed using environmental chamber.

C. *CO_2 Calibration Results*

The sensitivity curves shown in Fig. 5 are the calibration result acquired by carrying out the experimentation at Gas Sensors Lab using the setup shown in figure 4. The calibration was carried out by passing the known concentration of CO_2 in gas chamber after measuring the sensor output with synthetic air flushed into the chamber (corresponds to 0ppm). CO_2 concentration was increased in steps of 25 ppm each time. The change in EMF value as function CO_2 concentration from reference of synthetic air flushed in the chamber is illustrated in Fig. 5. This data was used to recalibrate the equations provided by the manufacturer in the data sheet.

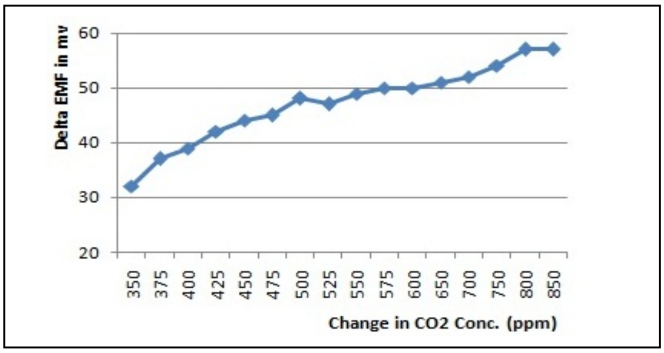

Fig.5. Change in EMF versus CO_2 concentration, with reference to 0ppm.

IV. SYSTEM PERFORMANCE EVALUATION

This section explains about the performance tests of the Envirobat performed under two environmental conditions. Two experiments were carried out to evaluate performance of the devices. During one of the experiments, we placed Envirobat device in a Seminar Hall at the Centre for Nano Science and Engineering (CeNSE) for a period of 29 hours wherein a conference was being conducted with audiences filling the hall and vacating occasionally during break times. Another experiment was carried out with CiSTUP team where two of the Envirobat devices were taken to Forest and Mountainous regions of Western Ghats of India for environmental studies. Both these field testing results are discussed in forthcoming subsections.

A. *Evaluation of Indoor air quality*

For indoor air quality measurement test, experiment was carried out by monitoring CO_2 concentration in the Seminar Hall of CeNSE for 29 hours continuously at a time when a two day conference was being conducted. The intent was to observe if the device could sense change in CO_2 concentration levels in the hall when it was fully occupied or when it was fully empty. The location of ENvirobat deployment in the seminar hall is shown in Fig. 6.

The conference was started at 9 AM on day 1 and day2 and ended at lunch time on day 2. The change in CO_2 levels indicating occupancy by attendees in seminar hall was clearly observed in Fig. 7. It is also interesting to note that CO_2 concentration increases by about 60ppm when the hall was fully occupied. The fluctuation in CO_2 level between 9 AM and 6 PM of the first day is attributed traffic of audiences for their tea breaks and lunch breaks. Region B, D and H correspond to tea break, lunch break on first day and tea break on second day respectively. Regions A, C, E, G and I show rise in CO2 level as human population fill the seminar hall. This pattern is repeated even next day starting 9.00 AM. The fall of CO_2 level in region F of the graph is attributed for night time between 6 PM of first day and 9 AM of second day when the hall was devoid of any human population. Although data was collected at periodicity of every minute, we show data every one hour to simplify the graph.

Fig. 6 Location of Envirobat in the Seminar hall

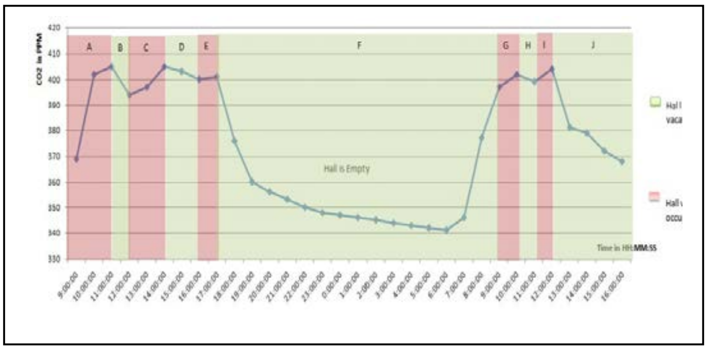

Fig.7. CO_2 concentration versus time for indoor air quality experiment

B. *Evaluation of Outdoor air quality*

For outdoor air quality measurement, Envirobat was taken to Western Ghat for environment air quality measurement with CiSTUP team. Two of the devices were taken for this study. One was mounted at a railway station for 48 hours where trains used to pass by (Fig. 8). There was no measurable change in CO_2 levels as the trains passed by.

Fig. 8 Deployment of the device in a railway station in Western Ghats

Another device was carried by a person during his local travel in the mountainous region at a stretch of around 15 Kms. Figure 9 shows the concentration of CO_2 measured while commuting at different locations at regular intervals of time. The CO_2 level was found to vary between 350 to 360ppm. Figure 10 shows temperature and humidity data collected from the same device for the same case study simultaneously while measuring CO_2 concentration level. The entire data collection was done by battery operated device that did not require any intermittent charging. The data was stored in the local memory storage card, and simultaneously transferred to the server.

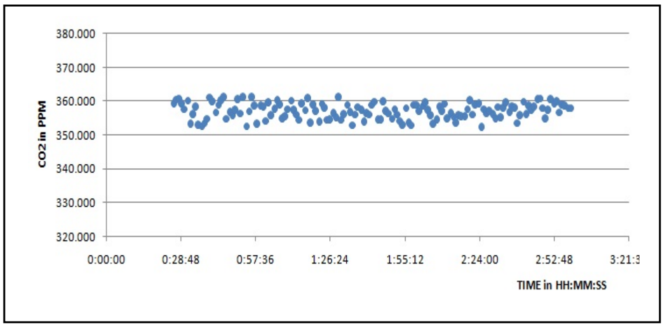

Fig. 9. CO_2 level measured in the outdoor air quality experiment .

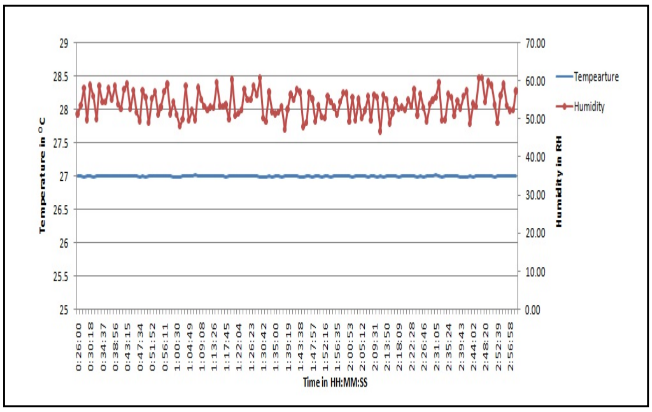

Fig.10. Temperature and humidity measured in the outdoor air quality experiment .

V. WIRELESS DATA COMMUNICATION & GRAPHICAL USER INTERFACE

In order to monitor the pollutant levels as sensed by Envirobat devices at regular intervals mounted at different locations, wireless data communication channel is established using GSM module. The data stored in local flash memory of devices are transmitted through GPRS to remote centralized server. GPS module provides physical location of the device at the time of sampling data acquisition. GPS data becomes significant if the device is mounted on a vehicle that is collecting air pollution level data at multiple locations as function of time. The user has option of setting periodicity of data sampling at his choice. The display and keyboard interface with Envirobat allows user to set periodicity of measurement as input to the device. Depending upon the periodicity of sending the data, GSM module transmits the data from flash through a UDP protocol.

Once the data is stored in a server it can be easily accessed by any user. A registered user can register and login to monitor pollution levels at different locations with device IDs known to them. The mounted devices are linked with Google map to show their exact physical locations based on GPS data. Also, analysis of the data can be plotted with convenient graphical user interface. Figure 11a and 11b show login page for the user and display of data of one device located at CeNSE department respectively. The web link for accessing Envirobat data is http://sindhu.ece.iisc.ernet.in/systemslab/envirobat.php.

Fig.11a. Login page for users to access Envirobat website

Fig.11b. Displayed air pollution data acquired from a device located at CeNSE Department.

VI. CONCLUSION AND FUTURE WORK

Envirobat device is designed with easy user interface with display and keyboard for setting up various parameters during measurement. Also SD card interface makes the data available to user immediately. The user has option of creating his customized setting for transmitting data at appropriate intervals. This version of Envirobat demonstrates monitoring urban air pollutants and logging the acquired data for online access. There is a great flexibility for user to access the data from the device. The online GUI provides better user experience by visualizing the graphs.

The future version of Envirobat would include a touch screen to give user a better experience. A Zigbee module which will enable the networking between the devices so that devices can talk among themselves and there could be a single master device that communicates with server through TCP/IP protocol. The device settings of measurement periodicity, data upload periodicity could be controlled remotely from a computer terminal remotely. A Bluetooth module to facilitate the wireless data communication with hand held mobile devices is being worked on. A dedicated RTOS would be implemented on the device. The Envirobat module could be customized to suite various applications in air quality monitoring, locating the sources of pollution, personalized exposure to air pollution levels for health tracking etc.

Acknowledgments

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REFERENCES

[1] Air quality assessment, emission inventory and source apportionment study for Bangalore city, Project Report No.2004EE28, 2010, www.terii n.org

[2] Karanataka State Pollution Control Board, http://kspcb.kar.nic.in/ambient_air_quality.htm

[3] Arun Kumar Mahodaya et al., Urban Air Quality Monitoring through Large Scale Wireless Sensor Networks, published at Conference on Infrastructure, Sustainable Transportation and Urban Planning - CiSTUP@CiSTUP 2010