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LARGE SCALE URBAN AIR QUALITY MONITORING USING WIRELESS SENSOR NETWORKS

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ABSTRACT

In the proposed paper, a wireless sensor platform was developed to addresses the problem of air pollution monitoring at a large scale. It is a Microcontroller PIC 16F877 based core with off the shelf sensors to detect gases like Sulphur Dioxide (SO_2), Carbon Monoxide (CO), Ammonia (NH_3), and Particulate matter (PM_{10}) in the air. It consists of Global System for Mobile Communications (GSM) wireless link and also a low-cost ZigBee module. Wireless sensor network formed with ZigBee links can be scaled up using the GSM connectivity to interface with the external world. Air Pollution monitoring is performed using a system of sensor nodes with the help of wireless communication via ZigBee protocol. A prototype version of the platform is realized and tested. The major problem of power consumption by the sensor nodes in the designed wireless sensor network is addressed. The results showed that the proposed system can provide fine quality of air pollutants information through the WSN technology.

Keywords: air quality monitoring, ZigBee protocol, wireless sensor networks, power consumption, sensor calibration, global system for mobile communications (GSM).

INTRODUCTION

With the rapid urbanization and industrialization process across the world, the problems related to environmental pollution become universal. Air Pollution [1] is the presence of harmful contaminants or pollutants in the air. Inhaling the pollutant air is dangerous for the human health causing difficulty in breathing, coughing and leading to many respiratory problems. Looking at the adverse effects of air pollution on the human health, design and development of low-cost air monitoring systems is the need of the day and attracting many researchers to work in this area.

Air pollution monitoring systems [2] will help the local governments or the policymakers to enforce laws for controlling the air pollutant levels for the well being of their citizens. Even though the traditional air pollution systems offer highly reliable and accurate data, they cannot provide the air pollution on the real-time basis. The drawbacks of conventional methods are their massive weight with tremendous size and expensive which provides only low resolution sensing data. These systems are not able to provide air pollution data of high spatiotemporal resolution due to non-scalability and limited data availability.

With the recent developments in the field of Integrated circuits and communications paved the way for the development of Wireless Sensor Networks (WSNs). WSNs are used extensively in the real-time applications without the human involvement to gather and examine the data smartly. In the present day, Wireless Sensor Networks [6] are widely used in all the commercial, industrialized and military applications. Wireless Sensor Network based air Quality monitoring systems are low cost, battery operated and capable of collecting the data on the real-time basis and received data can be made available on the internet to a broader audience.

Some of the existing air pollution monitoring solutions are presented as below:

Cambridge Mobile Urban Sensing, CamMobSense [3] is a low-cost system with low power ZigBee transceiver and a Data logger on board. It transfers the collected data to the central server through the gateway. It monitors temperature, humidity, noise, CO, NO_2, vehicle occupancy, position, movement. It is part of MESSAGE project, the collaboration between Cambridge University, Imperial College London, Leeds University, Newcastle University and Southampton University.

RAE systems [4] provided the solutions which have multi-gas sensing capability and are battery powered. These solutions are costly which a limitation for its large-scale deployment. Recordum solutions require higher power, form factor and weight of the device hinders its massive scale and ease of implementation.

ENVIROMOTE, [5] capable of detecting gases like CO_2, CO, NO_2, SO_2, and humidity. It is based on TI's MSP430 microcontroller core with off-the-shelf sensors. It supports a broader reach GSM network in addition to a low-cost ZigBee wireless link. Suitable for the large-scale deployment.

In the proposed paper, a prototype version of ZigBee based air quality monitoring system using the wireless sensor network technology is realized and tested. The experimental results showed the proposed system can provide fine quality of air pollutants information in real-time [9] through the WSN technology.

PROPOSED DESIGN

A. Hardware description

It is a battery operated wireless platform developed on Microcontroller PIC 16F877 with off the shelf sensors to detect gases like SO_2, CO, NH_3, and PM_{10} in the air. It consists of GSM wireless link and also a low-cost ZigBee module. Wireless sensor network formed with ZigBee links can be scaled up using the GSM connectivity to interface with the external world.

Figure-1 shows the block diagram of the proposed design with various sub-modules on the platform.

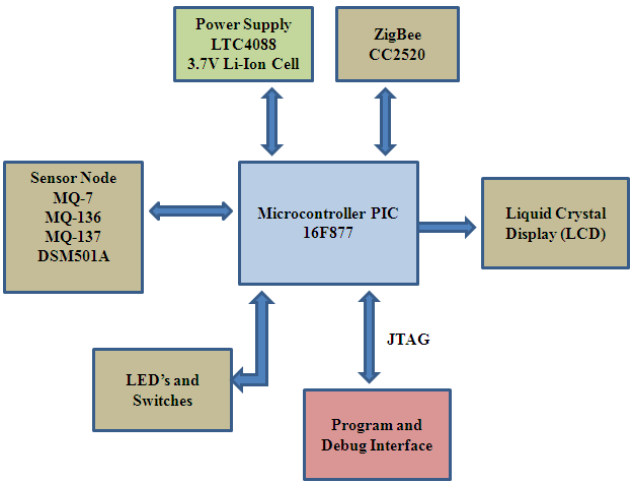

Figure-1. Block Diagram of the transmitter.

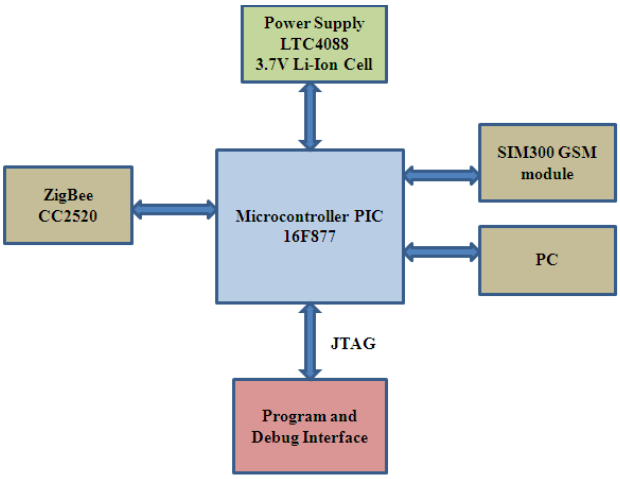

Figure-2. Block diagram of the receiver.

The Wireless Sensor Mote consists of Microcontroller PIC 16F877, a GSM module, a Zigbee module, LCD interface, Sensor Interface with associated signal conditioning circuitry and the power supply.

a) Microcontroller: PIC 16F877 is one of the most advanced microcontrollers from Microchip. It is widely used for experimental and modern applications because of its low price, high quality, and ease of availability suitable for wide applications. On. PIC Microcontroller is interfaced with various modules like Sensor mote, GSM module, Zigbee radio, power supply, LCD, and PC. It generates the respective I/O and Controls signals for the various modules.

b) GSM Module: It is widely used mobile communication system in the world. GSM is an open and digital cellular technology used for transmitting mobile voice and data services operates at the 850MHz, 900MHz, 1800MHz and 1900MHz frequency bands. In the proposed design SIM300 GSM module [13] is used for establishing connectivity and communication of the data. GSM Module is interfaced with PIC Microcontroller 16F877 over Universal Synchronous Asynchronous Receiver Transmitter (USART).

c) ZigBee: A 2.4 GHz IEEE 802.15.4 Zigbee radio CC2520 from the Texas Instruments (TI) [6] is used in the proposed design. Zigbee radio CC2520 is suitable for the design of the mote of low power and short-range communication. The Zigbee radio CC2520 is operated at 2.7V to reduce the power consumption.

d) LCD Interface: Liquid Crystal Display (LCD) screen is an electronic display module which finds its application in various electronic displays. A 16x2 Liquid Crystal Display is used in the design which can display 16 characters per line and there are 2 such lines with each character is displayed in 5x7 pixel matrix.

d) Sensor Nodes: In the proposed design, the sensors used are MQ-7, MQ-136, MQ-137, DSM501A for monitoring the concentration levels of Carbon monoxide in PPM, Sulphur Dioxide levels in PPM, Ammonia in PPM and the Particulate matter PPM_{10} in $\mu g/m^3$. Design of the sensor node requires the four basic functionalities to be implemented: Signal Conditioning, Sensing the Environment, Signal Amplification, and Signal Calibration.

e) Power supply Unit: Hardware is a battery operated wireless platform developed on Microcontroller PIC 16F877 with off the shelf sensors to detect gases like SO_2, CO, NH_3, and PM_{10} in the air. Power supply Unit consists of 3.7V Li-Ion cell with Li-Ion battery charger (LTC4088) generates the required supply voltage for the Transmitter and receiver part.

Figures 3 and 4 shows the transmitter and receiver section of the designed air pollution monitoring system.

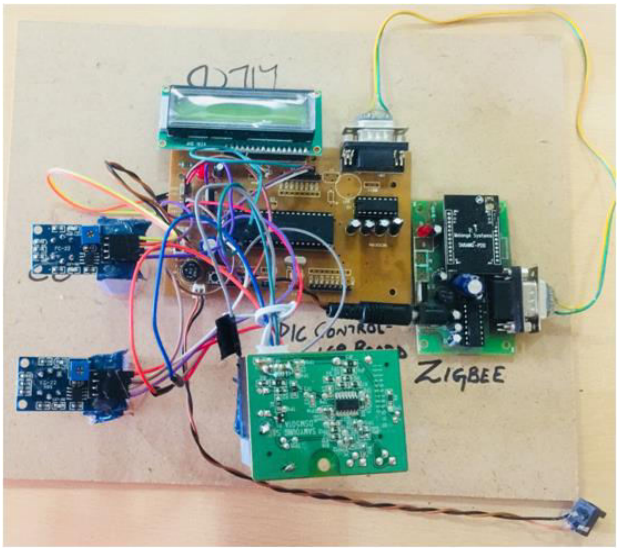

Figure-3. The prototype of the transmitter section.

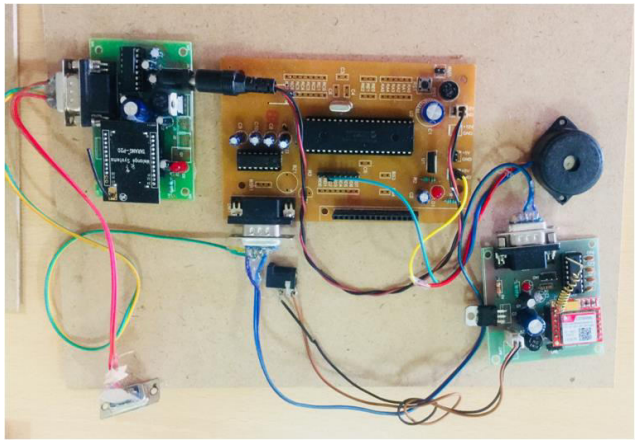

Figure-4. The prototype of the Receiver section.

f) Buzzer: A buzzer or beeper is a signaling device, usually electronic, typically used in automobiles, household appliances. It consists of many switches or sensors connected to a control unit to sound a warning in the form of a intermittent or continuous beeping sound. Components used in the proposed design are shown in Table-1.

Table-1. Components used in the project.

S. No.	Components
1	CO Sensor - MQ-7
2	SO_2 Sensor - MQ-136
3	NH_3 Sensor - MQ-137
4	PPM_{10} Sensor - DSM501A
5	Microcontroller PIC 16F877
6	ZigBee Module CC2520
7	GSM Module - SIM300
8	16x2 LCD display
9	Electronic Buzzer

B. Software description

MPLAB® X IDE is a Integrated Development Environment (IDE) software program that runs on a PC (Windows®, Mac OS®, Linux®) to develop applications for Microchip microcontrollers and digital signal controllers. It is an because it provides a single integrated "environment" to generate code for embedded microcontrollers. Microcontroller code schedules the turn ON and turns OFF of various modules in the design through an Interrupt Service Routine.

POWER AND COST ESTIMATE

A. Power estimation

Power estimation of the wireless mote is an essential aspect as it is a battery-powered device and is intended to be deployed in different locations. Table-2 shows the power breakup of different sub-modules 2. It is observed that the sensors are the most power hungry components followed by the GSM module. They both together amount to more than 50% of total power consumption. Hence a strategy to intermittently power up these components is crucial. The battery capacity is 8000mAh. Neglecting the power consumption of other peripherals, the battery lifetime is 28 days.

Table-2. Power consumed by various components.

S. No.	Component	Power/Energy
1	CO Sensor	750mW
2	SO_2 Sensor	<340mW
3	NH_3 Sensor	750mW
4	PPM_{10} Sensor	90mA @ DC Voltage 5V
5	Microcontroller PIC 16F877	0.6mA @ DC Voltage 3V
6	ZigBee Module	81mW
7	GSM Module	3.045W
8	LCD	5mA @ DC Voltage of 5V

B. Cost estimation

Cost estimation was performed to conclude the final approximate price of one wireless platform is approximately INR 15000. Table-3 lists the cost breakup of different modules. The significant cost of the prototype is due to high cost of sensors. In bulk production of these modules, the price is expected to reduce further.

Table-3. Cost breakup.

S. No.	Component	Cost per unit
1	CO Sensor	650
2	SO_2 Sensor	1000
3	NH_3 Sensor	650
4	PPM_{10} Sensor	4000
5	Microcontroller PIC 16F877	100
6	ZigBee Module	350
7	GSM Module	2200
8	LCD	275

RESULTS AND DISCUSSIONS

The designed air pollution monitoring wireless sensor mote was placed in the Lab room at Faculty of Science and Technology, IFHE campus, Hyderabad. It was tested rigorously and continuously for of one hour, one week and one month. The data was acquired through SMS and LCD. The observed data is plotted through Matlab concerning air pollutant concentrations in durations of Hours, weeks and Months. The concentration levels correspond approximately to the ambient environment. In the observed results, there are some

deviations because of incorrect calibration data for the sensors. Proper calibration of the sensors is required to capture the accurate results of the gas concentrations. However, the results of designed setup are promising concerning the performance and capability to obtain the data as a pollution monitoring device. Wireless sensor network [10] formed with ZigBee links can be scaled up using the GSM connectivity to interface with the external world. Air Pollution monitoring is performed using a system of sensor nodes with the help of wireless communication via ZigBee protocol [7]

Figure 5, 6, 7 and 8 shows the plot of data acquired by the mote for PPM_{10}, SO_2, NH_3, and CO sensors respectively for one Hour.

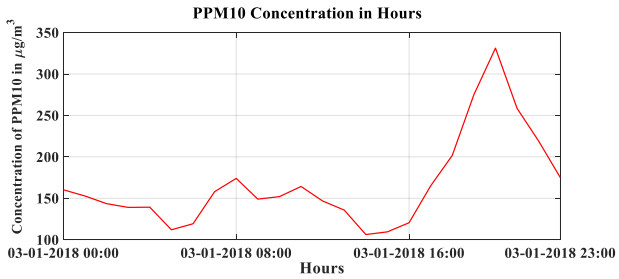

Figure-5. Hourly concentration of PPM_{10} in μg/m^3.

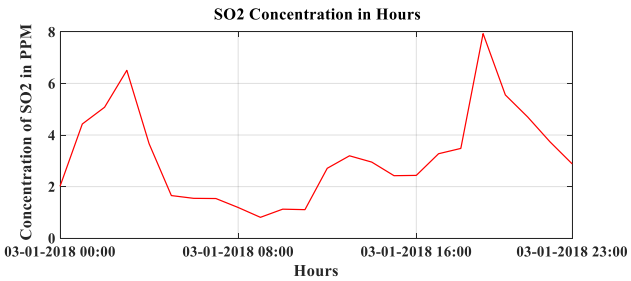

Figure-6. Hourly concentration of SO_2 in PPM.

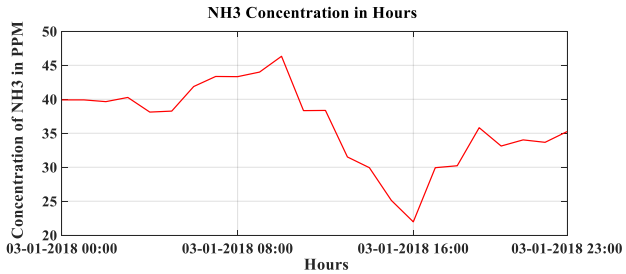

Figure-7. Hourly concentration of NH_3 in PPM.

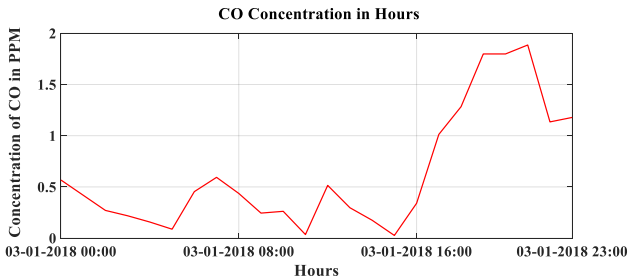

Figure-8. Hourly concentration of CO in PPM.

Figure 9, 10, 11 and 12 shows the plot of data acquired by the mote for PPM_{10}, SO_2, NH_3, and CO sensors respectively for one week.

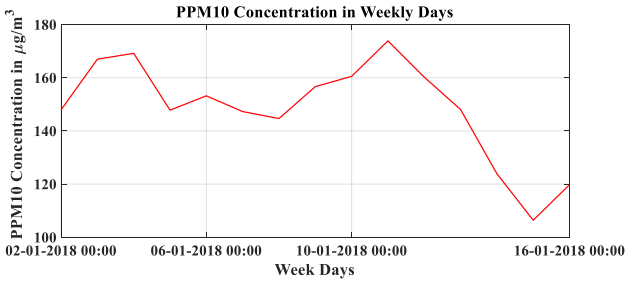

Figure-9. Weekly concentration of PPM_{10} in μg/m^3.

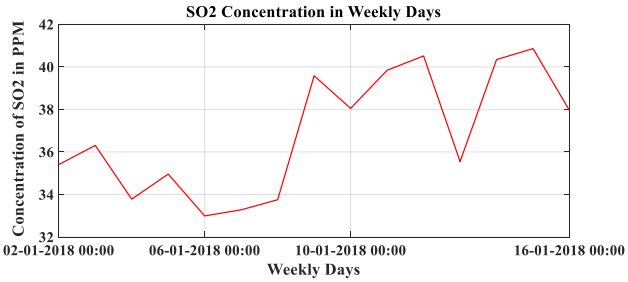

Figure-10. Weekly concentration of SO_2 in PPM.

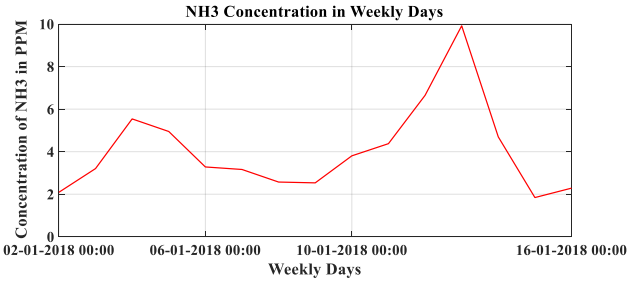

Figure-11. Weekly concentration of NH_3 in PPM.

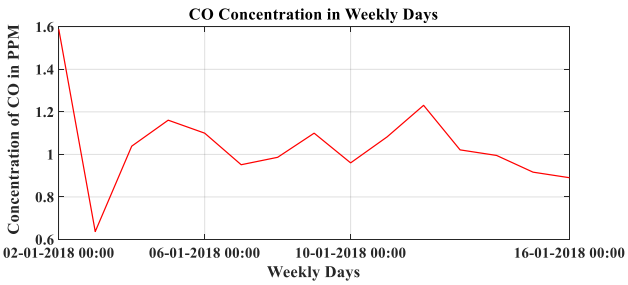

Figure-12. Weekly concentration of CO in PPM.

Figures 13, 14, 15 and 16 shows the plot of data acquired by the mote for PPM_{10}, SO_2, NH_3, and CO sensors respectively for one Month (Jan-Feb, 2018).

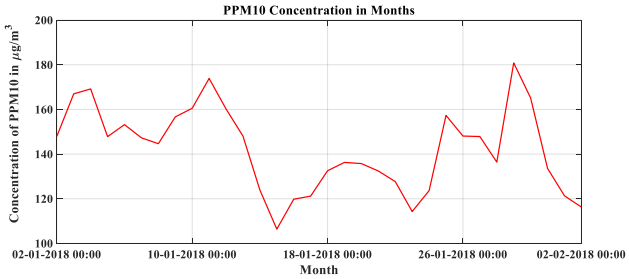

Figure-13. Monthly concentration of PPM_{10} in $\mu g/m^3$.

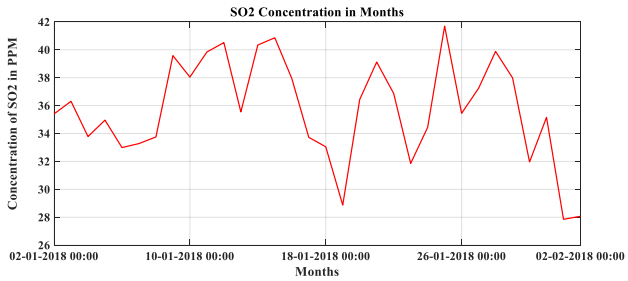

Figure-14. Monthly concentration of SO_2 in PPM.

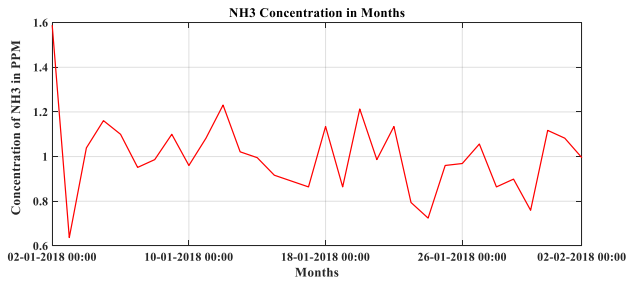

Figure-15. Monthly concentration of NH_3 in PPM.

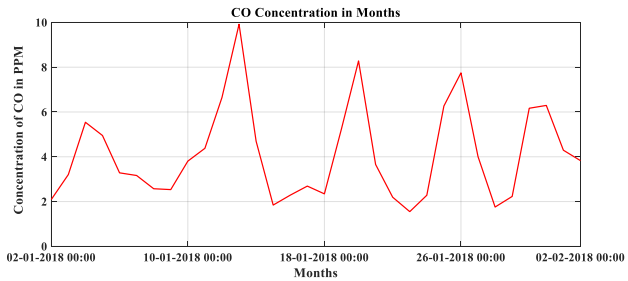

Figure-16. Monthly concentration of CO in PPM.

CONCLUSIONS

A wireless sensor platform was developed to addresses the problem of air pollution monitoring. It is a Microcontroller PIC 16F877 based core with off the shelf sensors to detect gases like Sulphur Dioxide (SO_2), Carbon Monoxide (CO), Ammonia (NH_3), and Particulate matter (PM_{10}) in the air. It consists of Global System for Mobile Communications (GSM) wireless link and also a low-cost ZigBee module. Wireless sensor network formed with ZigBee links can be scaled up using the GSM connectivity to interface with the external world. Air Pollution monitoring is done using a system of sensor nodes with the help of wireless communication via ZigBee protocol. A prototype version of the platform is realized and tested. The initial version has been proven to work as per the requirements concerning low power and low cost. The designed prototype has rigorously tested for the measurement of air pollutants, and the platform is cost-effective which can be deployed on a large scale. The experimental results show that the proposed system can able to provide finest details of air pollutants in real-time through the WSN technology.

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