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Implementation Of Zigbee Based Wireless Air Pollution Monitoring System

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Abstract—

An Environmental Air Pollution Monitoring System for monitoring the concentrations of major air pollutant gases has been designed, developed, and tested complying with the Zigbee standard. This system measures concentrations of gases such as CO, NO2 and SO2, and using semiconductor sensors. The hardware unit integrates a single-chip microcontroller, air pollution sensors array, a Zigbee Modem and a Global Positioning System Module (GPS-Module). The Central-Server is a high-end personal computer application server with Internet connectivity. The hardware unit gathers air pollutants levels (CO, NO2, and SO2), and packs them in a frame with the GPS physical location, time, and date. The frame is subsequently uploaded to the Zigbee-Modem and transmitted to the Central-Server via zigbee network. The Central-Server is interfaced to Google Maps to display the location of hardware unit. The system was successfully tested in the city of Nagpur, India.

Keywords-Air pollution Monitoring; Zigbee; Sensors; Real Time

I. INTRODUCTION

Generally, the pollution has been defined as the presence of a substance in the environment that because of its chemical composition or quantity prevents the functioning of natural processes and produces undesirable environmental and health effects[3].In other words, pollution can causes instability, disorder, harm or discomfort to the physical systems or living organisms they are in[4].With the fast development of the industrialization and urbanization process in the world, environmental pollution problems become one of the common topics in all country of the world. At present, there are air pollution, water pollution and soil pollution in worldwide. This thesis only discusses air pollution. Air pollution is the presence of contaminants or pollutant substances in the air that interfere with human health or welfare, or produce other harmful environmental effects[5].These pollutant substances usually result from vehicle emissions, Industrial emissions and volatile organic compounds. There are various issues of air pollution, and Most of all are health-related issues. In other words, clean air is a basic condition for health. The health issues caused by air pollutants may range from subtle biochemical and physiological changes to difficulty in breathing, wheezing, coughing and aggravation of existing respiratory and cardiac conditions. The World Health Organization states that 2.4 million people die each year from causes directly attributable to air pollution, with 1.5 million of these deaths attributable to indoor air pollution[6]. Based the fact above mentioned, the human should focus on air pollution monitoring.

In the area, there are two methods to use to monitor air pollution at present. The one is passive sampling (nonautomatic), and the other is continuous online monitoring (automatic). The advantage of the passive sampling method lies in that the monitor equipment is simple and inexpensive, but it can only get on-site monitoring parameters in a certain period, can not provide real-time values. Meanwhile, the results of monitoring effect by the man factor largely and it will seriously damage the health of the monitoring man in the site of high concentration of harmful substances. The procedure of continuous online monitoring method is as follows: use sensors to monitor the parameters, and then send to the control center by network. The way of data transfer include both wired and wireless. The wired way usually uses public telephone network, or fiber-optic to realize data transmission. Although this method is stable and reliable, with high speed of data transmission, but the shortcomings of the method is also obvious in a wide and dynamic range, such as complex network cabling, expensive,etc.

With the rapid development of communication technology, network technology and remote sensing technology, there is a trend that air pollution monitoring system is often designed in wireless mode. At present, the wireless mode in air pollution monitoring system includes GSM, GPRS, etc. But these modes are high cost in both installation and maintenance, and complexity. In the other hand, Wireless sensor network have been rapidly developed during recent years. Starting from military and industrial controls, its advantages include the liability, simplicity, and low cost[7]. Based on these advantages, it is now being applied in environmental monitoring. In air pollution monitor applications, Jong-Won Kwon et al. Designed an air pollution monitoring system using ZigBee networks for Ubiquitous-City. They focus on implementation of air pollution monitoring system, and developed an integrated wireless sensor board which employs dust, CO2, temperature/humidity sensor and a ZigBee module[8]. In China, Zhang Qian et al. compared the advantages of ZigBee with other two similar wireless networking protocols, Wi-Fi

and Bluetooth, and proposed a wireless solution for greenhouse monitoring and control system based on ZigBee technology[7]. Geng Jun-tao et al. introduced the application background and research actuality of wireless sensor network in atmosphere environment monitor, designed the node hardware structure, and discussed the architecture and the system software of the atmosphere environment monitor system[9].Although some researchers have attempted to use wireless sensor network technology, such as ZigBee, to monitor the air pollution, its application in air pollution monitoring remain few.

The paper reviews the development of the technology of the wireless sensor network and ZigBee, focusing on the requirements of air pollution monitoring system. Based on the above mentioned, the application schema of ZigBee based wireless sensor network is discussed and implmented.

II. AIR QUALITY

In a general way, it is possible to describe the atmosphere as a very thin gaseous film, where all the meteorological phenomena that regulate the human life occur. Filled with a great diversity of molecules (Table I), the atmosphere performs, at the same time, a role of protection and regulation. Air pollution can have various definitions. According to [6], "air pollution means the presence, within the external atmospheres, of one or more contaminants, or its combination in quantities or with a temporal duration that can become harmful to human life, vegetable, animal or goods. The air contaminants include smokes, steams, paper hashes, dusts, soot, carbonic smokes, gases, fogs, radioactive material or toxic chemical products."

Certain atmospheric pollutants react with each other creating others pollutants called secondary pollutants. The dissociation, trough the sun's effect, of volatiles organic compounds, carbon monoxide and nitrogen oxide, produced by automobile's motors, lead to the formation of ozone, essentially during the summer, when temperature reaches higher levels.

TABLE I. AVERAGE COMPOSITION OF PURE AIR

Element	Symbol	Proportion
Nitrogen	N_2	78.084%
Oxygen	O_2	20.946%
Argon	Ar	0.943%
Carbon dioxide	CO_2	340 ppm
Neon	Ne	18.18 ppm
Helium	He	5.24 ppm
Methane	CH_4	1.5 ppm
Krypton	Kr	1.14 ppm
Hydrogen	H	0.50 ppm
Oxide Nitrous	N_2O	0.40 ppm
Xenon	Xe	0.09 ppm

Air pollution has dramatic consequences for human health,
leading to respiratory problems and even death [6] and for the environment like the greenhouse effect, acid rains and ozone layer reduction .

The European Community has dedicated special attention to the problem of the most representative pollutants concentration, such as the case of Carbon Monoxide (CO), Nitrogen Dioxide (NO2), Sulphur Dioxide (SO2), Ozone (O3) and particles of 10 μm or less (PM10) and special Regulations have been produced.

Although the Carbonic Dioxide (CO2) isn't considered a pollutant, its concentration has also to be quantified, due to importance of this gas to the planet's ecosystems.

The system presented here is capable of measuring the following gases in the atmosphere:

• Carbon Monoxide (CO) – Carbon Monoxide is a colorless and odorless gas. It is mainly due to automobile traffic, industrial activity and volcanic eruptions. This gas affects cardiovascular and nervous systems and, in large concentrations, inhibits the blood's capacity of exchange oxygen with vital organs. In extreme cases, may provoke death by poisoning.

• Sulphur Dioxide (SO2) – Sulphur Dioxide is a colorless gas, detectable by the distinct odor and taste. Like CO2, it is mainly due to fossil fuels burning and to industrial processes. In high concentrations may cause respiratory problems, especially in sensitive groups, like asthmatics. It contributes to acid rains.

• Nitrogen Dioxide (NO2) – Nitrogen Dioxide is a brownish gas, easily detectable for its odor, very corrosive and highly oxidant. It is produced as the result of fossil fuels burning. Usually NO thrown to the atmosphere is converted in NO2 by chemical processes. In high concentrations, NO2 may lead to respiratory problems. Like SO2, it contributes to acid rains.

III. ZIGBEE STANDARD

The ZigBee is the new short range, low power, low data rate wireless networking technology for many applications. It is best specified the bottom three layers (Physical, Data Link, and Network), as well an Application Programming Interface (API) based on the 7-layer OSI model for layered communication systems.

Figure-1 shows the layered protocol architecture adopted by the alliance. It should be noted that the ZigBee Alliance chose to use an already existing data link and physical layers specification. These are the recently published IEEE 802.15.4 standards for low rate personal area networks.

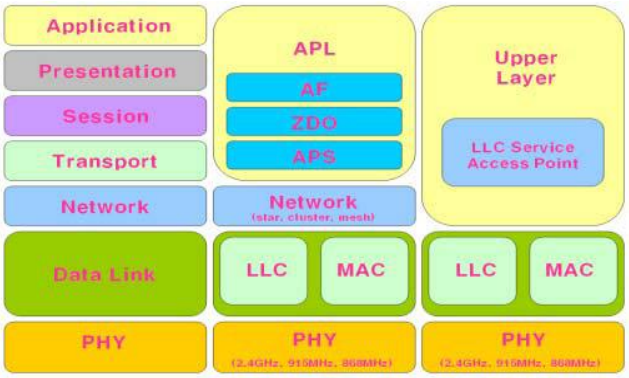

Figure 1. Protocols stack for layered wireless Communication

A communication network is composed of many nodes, each of which can transmit and receive data over communication links, wireless or cabled supports network topologies. The ZigBee network layer supports star, tree and mesh topologies. The ZigBee coordinator is responsible for initiating and maintaining the devices on the network, and all other devices, known as end devices, directly communicate with the ZigBee coordinator. In mesh and tree topologies, the ZigBee coordinator is responsible for starting the network and for choosing certain key network parameters but the network may be extended through the use of ZigBee routers. In tree networks, routers move data and control messages through the network using a hierarchical routing strategy.

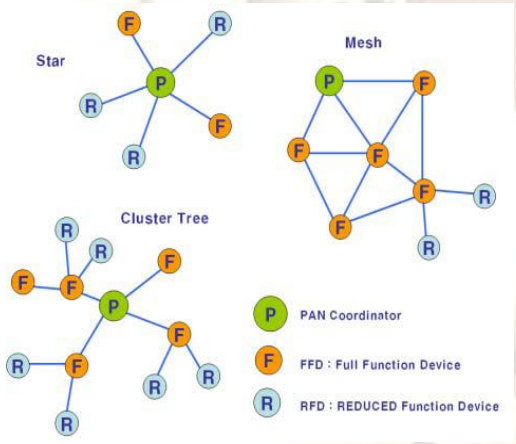

Figure 2. Topologies for ZigBee

The IEEE 802.15.4 standard defines three frequency bands of operation: 868MHz, 916MHz and the 2.4GHZ bands for ZigBee. 2.4GHz bands are used the most commonly available wireless communication products throughout the world because of ISM (Industrial, Scientific, Medical) band. In addition this band offers the highest achievable data rate of 250Kbps and 16 channels between 2.4GHz and 2.4835GHz at the physical layer. Typical transmission distances are within the range from 30 meters in an indoor non-line of sight environment to over 100 meters in a line of sight environment. But problems related a range can be solved through applying routing algorithm at the network layer.

Frequency	Band	Coverage	Data rate	Ch	Rx Sensitivity	Modulation
2.4 GHz	ISM	Worldwide	250 Kbps	16	-85dbm	O-QPSK
868 MHz		Europe	20 Kbps	1	-92dbm	BPSK
915 MHz	ISM	Americas	40 Kbps	10	-92dbm	BPSK

Figure 3. Frequency bands for ZigBee

Although defined as 25mW in the world, transmit output power of ZigBee is limited within 10mW. Therefore ZigBee modules employ dipole type antenna to increase gain of antenna.

IV. HARDWARE ARCHITECTURE

The proposed system is designed by integrating the following hardware modules shown in Fig. 4. As the figure shows, the system consists of a PIC16F877A microcontroller integrated with a sensor array using analog ports. The hardware unit is also connected to a GPS module and a Zigbee-Modem using the RS-232 interface. Each of these components is described in the following.

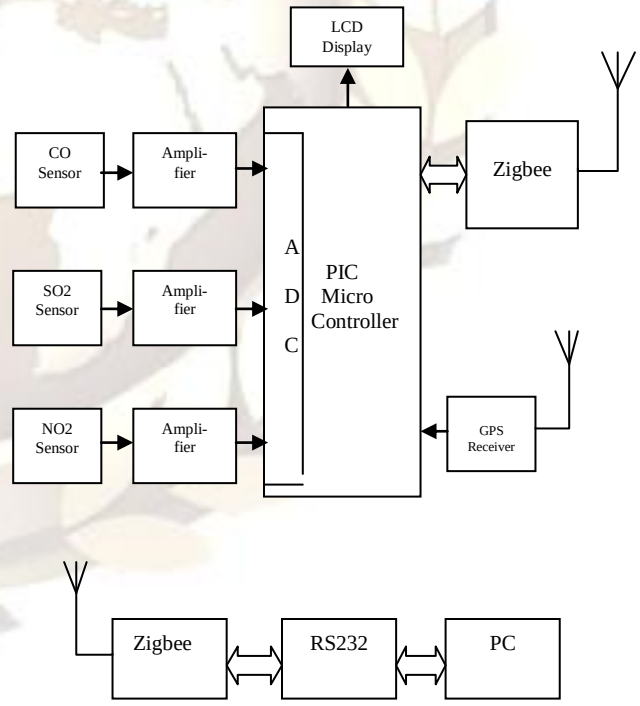

Figure 4. System hardware basic building blocks.

TABLE II. SENSOR ARRAY SPECIFICATION

Sensor	CO	NO2	SO2
Resolution (ppm)	< 1.5	< 0.02	< 0.1
Resp. time (t90)(s)	< 25	< 60	< 25
Op. range (ppm)	0-1000	0-200	0-200
Operating life (yrs)	> 2	> 2	> 2
Diameter (mm)	20	20	20

A. PIC16F877A microcontroller

The PIC16F877A microcontroller is the main component of a pollution detection unit [10]. The operating system that runs inside the chip coordinates the substances measurement process, the acquisition of the GPS coordinates and the data transmission to the central server [11]. The microcontroller is mounted on a development board that provides an RS232 serial communication to the Zigbee modem and GPS receiver and a parallel connection to the gas sensors.

The connection between the gas sensors and the PIC16F877A microcontroller can't be made directly because of the very small output voltages provided by the sensors (mA).This problem is solved by using auxiliary electronic circuits for signal conversion like OA (*Operational Amplifiers*) and transistors.

B. Sensors Array

The sensor array consists of three air pollutions sensors including Carbon Dioxide (CO2), Nitrogen Dioxide (NO2), and Sulfur Dioxide (SO2) [10]. As Table II shows, the resolution of these sensors is sufficient for pollution monitoring. Each of the above sensors has a linear current output in the range of 4 mA–20 mA. The 4 mA output corresponds to zero-level gas and the 20 mA corresponds to the maximum gas level. A simple *signal conditioning circuit* is designed to convert the 4 mA–20 mA range into 0–5 V to be compatible with the voltage range of the built-in analog-to-digital converter in the PIC microcontroller.

C. GPS Reciever

The GPS module provides the physical coordinate location of the mobile-DAQ, time and date in National Marine Electronics Association (NMEA) format [11]. NEMA format includes the complete position, velocity, and time computed by a GPS receiver where the position is given in latitude and longitude [12]. The data packet from the GPS-Module includes an RMS Header followed by UTC time, data validity checksum, latitude, longitude, velocity, heading, date, magnetic variation and direction, mode, and checksum. The only information required for the proposed system is date, time, latitude and longitude. The GPS modem is interfaced with the microcontroller using the RS-232 communication standard.

D. Zigbee Modules

In this paper, two types ZigBee modules are used to organize a network for air pollution monitoring system. The network is controlled by devices called the ZigBee coordinator modem(ZCM). The ZCMs are responsible for collecting data and maintaining the other devices on the network, and all other devices, known as Zigbee end devices(ZED), directly communicate with the ZCM.

The ZigBee module is hardware platform of wireless device. The modules realize the basic function of Physical and MAC layer, such as transmit and receive, modulation and demodulation, channel and power control. They operate at 2.4GHz frequency ISM band wireless communication. The modules include a digital direct sequence spread spectrum base band modem and an effective data rate of 250 kbps.

They employ the EM2420 2.4GHz radio frequency transceiver and the ATMEL 8-bit AVR microcontroller. They also exhibit a nominal transmit of -1.5dBm and a receive sensitivity of -92dBm When powered at 3.0V, the modules draw 31.0mA in transmit mode and 28mA in receive mode. When the entire module is in sleep mode, the current draw is reduced to approximately 10uA.

E. Central Server

The Central-Server is an off-the-shelf standard personal computer with accessibility to the Internet. The Pollution-Server is connected to the Zigbee-Modem via RS-232 communication standard. The air pollution information sent from each ZED are collected to ZCM. And then the data are saved to database of central server.

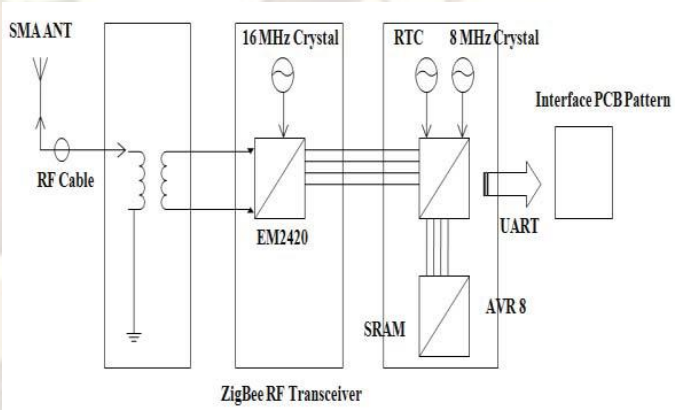

Figure 5. Block diagram of ZigBee module

Clients such as the municipality, environmental protection agencies, travel agencies, insurance companies and tourist companies can connect to the Central-Server through the Internet and check the real-time air pollutants level using a normal browser on a standard PC or a mobile device. The Pollution- Server can be physically located at the

Environmental Protection Agency (EPA) or similar government agencies.

V. SYSTEM IMPLEMENTATION AND THE RESULTS

The designed sensor array consisting of CO, SO2, and NO2 was interfaced through a signal conditioning circuit to the PIC16F877A microcontroller, as shown in Fig. 4

The sensor output voltages representing the level of gas for each pollutant were converted to a ppm value for each gas and simultaneously displayed on the LCD display of the hardware.

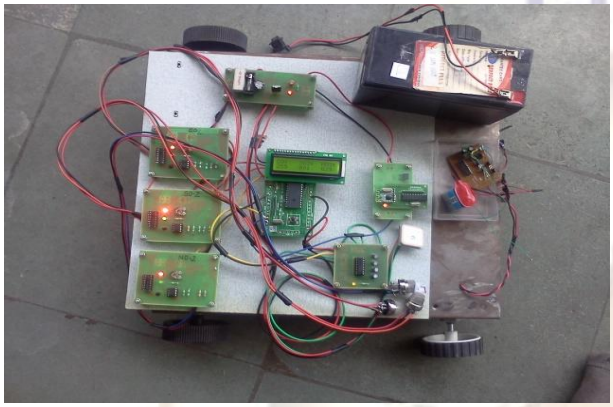

Figure 5. Prototype Hardware.

The GPS module and the Zigbee-Modem was connected to PORTC of the microcontroller. Fig. 5 shows the typical prototype hardware model. The hardware was placed on a remote controlled rover operating at the RF.

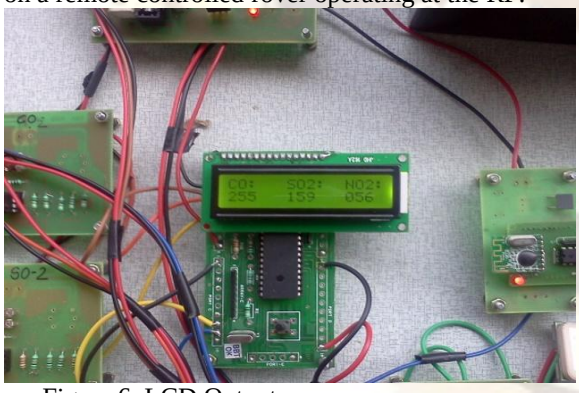

Figure 6. LCD Output.

The system can be used for monitoring the concentration of gases both at the indoor as well as at the outdoor environment.

While the rover is on the move, the microcontroller generates a frame consisting of the acquired air pollutant level from the sensors array and the physical location that is reported from the attached GPS module. The pollutants frame is then uploaded to the Zigbee Modem and transmitted to the Central-Server via Zigbee network.

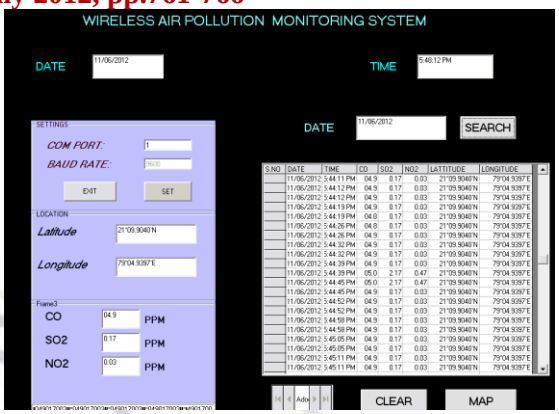

Figure 7. Receiver Output.

The Zigbee modem connected to the central server receives the transmitted frame via RS-232 interface and the pollutant data was displayed on the central server as shown in Fig. 7. The output was displayed in Visual Basics of latest version. In Fig. 7. the gases levels are shown in terms of percentage of particular gas in the atmosphere. The right window in the fig shows the COM PORT selected, Baud Rate,location that is latitude and longitude of the hardware as well as the gas concentration levels. While the left window shows the history of the gas pollutants measured and stored previously.

As Fig. 7. Shows, a user after entering a particular date in the search option can retrieve pollutant levels on that particular date. The central server is interfaced to Google Maps to display the location of harware in large metropolitan areas. The system was successfully tested in the city of Nagpur, India. The system reports real time pollutants level on a 24-h/7-day basis.

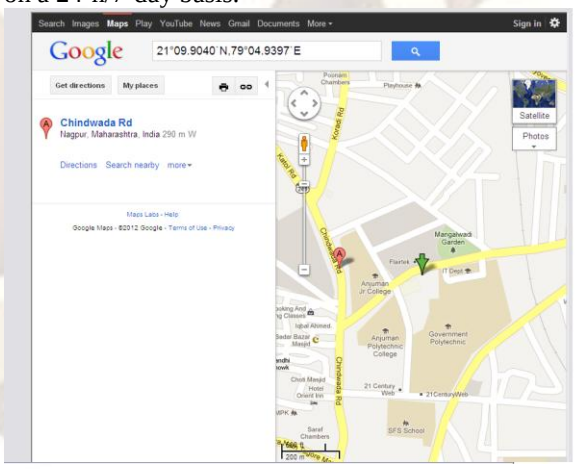

Figure 7. Hardware location on Google map

VI. CONCLUSION

A wireless air pollution monitoring system was designed, implemented and tested using the Zigbee network. The main purpose of this paper is that to introduce a new method for air pollution monitoring. Wireless Air Pollution

Monitoring System provides real-time information about the level of air pollution in these regions, as well as provides alerts in cases of drastic change in quality of air. This information can then be used by the authorities to take prompt actions such as evacuating people or sending emergency response team.The system utilizes remote controlled rover to collect pollutant gases such as CO, NO2, and SO2. The pollution data from sensor array is transmitted to a central server that makes this data available on the Internet. The data shows the pollutant levels and their conformance to local air quality standards. The usage of the semiconductor sensors adds several advantages to the system such as low cost, quick response, low maintenance, ability to produce continuous measurements, etc.

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