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Design and Development of ZigBee based Wireless Sensor Network for Monitoring Air Pollutants

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Abstract – The basic aim of this paper is the design of a low power wireless sensor network and control of inter-node data reception for use in the real time acquisition and communication of air pollutants such as SO_2, CO, NO_2 and NO etc. The network consists of end devices with sensors, routers that propagate the network over long distances, and a coordinator that communicates with the computer. The design is based on ARM 7 based LPC2378 microcontroller and EZ430RF 2480 ZigBee module to process communicate the data effectively with low power consumption. Also, extensive studies were performed to reduce data packets loss and Priority is given to power consumption and sensing efficiency, which is achieved by incorporating various smart tasking and power management protocols. The main objective is achieved by interfacing various sensors to measure the common air pollutants. The measured data is displayed on the monitor using the graphical user interface (GUI) .

Index Terms— Environmental, ARM Processor, Wireless Sensor Network , ZigBee module, Air pollutants ,Sensor nodes, Embedded system, Graphical User Interface(GUI).

1.INTRODUCTION

The unprecedented growth of industries and vehicular traffic have seriously affected the purity of clean air and environment. The world health organization announced that nearly 2.4 million people die every year due to this air pollution. So, the air pollution has become one of the greatest challenges for human health in the world[1]. The major components of air pollutants are particulate matter, SO_2, CO_2, CO and NO_x (i.e NO_2 and NO) etc. Methylene chloride is a VOC emitted from products such as paint strippers. Benzene, also an organic compound, is a known human carcinogen emitted from tobacco smoke and stored fuels. Finally, perchloroethylene is the chemical most widely used in dry cleaning and represents danger to our health. Reducing emissions of volatile organic compounds (VOCs) is of increasing importance to many companies using paint, varnish, ink, adhesives, cleaning liquids and other solvent based resources in their process. Certain atmospheric pollutants react with each other and produce other pollutants called secondary pollutants. Though carbon dioxide (CO_2) is not considered as an air pollutant, it is considered here due to its importance in green house effect.

There are various methods in practice to measure the air pollutants like gas chromatography (GC) and mass spectroscopy (MS) and Fourier transform infrared instruments (FTIIs) etc. These methods provide accurate and selective gas reading. But the high cost, large size and time consumption are the limitations. Due to these reasons researchers started designing embedded systems with readily available low cost gas sensors having fast response and also cost effective. A list of sensors used in the present work along with their features are presented in Table 1.

With the advancements in network technologies, the wireless sensor network (WSN) is found to be an efficient method of measuring and monitoring air pollutants [2]. This WSN is one of the most significant technologies in 21st century. A WSN is a system comprised of radio frequency (RF)

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transceivers, sensors, microcontrollers and power sources. Recent advances in wireless sensor network technology have led to the development of low cost, low power multifunctional sensor nodes. There are various technologies available for WSN , viz ., Wi Fi, ,Bluetooth, and ZigBee etc. It is an undisputed fact that Zigbee has many advantages over other methods. To name a few, it operates in industrial scientific and medical (ISM) band of 2.4 GHz,and it is low cost, high reliability , very long battery life, high security, self-healing properties,, large number of nodes supported , ease of deployment , guaranteed delivery , route optimization[3].

TABLE 1

LIST OF SENSORS AND THEIR FEATURES USED IN THE DESIGN

S.No	Name of the sensor	Manufacturer	Operational Range	Sensitivity
1	TGS2442 CO sensor (Semiconductor)	FIGARO,USA INC	30 ~ 1000 ppm	(change ratio of Rs) : 0.13 ~ 0.31
2	TGS 2106 NO_2 Sensor (Semiconductor)	FIGARO,USA INC	0.1 ~ 10 ppm	2.0 ~ 7.0
3	TGS 2201 NO_X Sensor	FIGARO,USA INC	0.1 ~ 10 ppm	Rs 0.3 ppm of NO_2
4	TGS4161 CO_2 Sensor	FIGARO,USA INC	350~10,000 ppm	44 ~ 72 mV
5	SO_2 Sensor	Alphasense, UK	0 to 100 ppm	300 to 440 nA/ppm
6	TGS 823 VOC Sensor	FIGARO,USA INC	50 ~ 5000 ppm	0.3 ~ 0.5

Multi-hop communication over the ISM band is also possible in WSN since it consumes less power than traditional single hop communication . A communication network is composed of many nodes each of which can transmit and receive data over communication links. 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. The IEEE 802.15.4 standard defines three frequency bands of operation : 868 MHz, 916 MHz and the 2.4 GHz bands for ZigBee. 2.4 GHz bands are used in most of the commonly available wireless communication devices globally because of ISM band. In addition, this band offers the highest data rate of 250Kbps and 16 channels between 2.4 GHz and 2.4835 GHz 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. Although defines as 25mW, transmit output power of Zig Bee is within 10mW. Hence, the Zig Bee modules employ dipole type antenna to increase gain of the antenna.[4].

In the present work WSN is achieved based on ZigBee. This ZigBee standard is built on top of the IEEE 802.15.4 standard. The IEEE 802.15.4 standard defines the physical and MAC (Medium Access Control) layers for low rate wireless personal area network .

2.HARDWARE DETAILS

The block diagram of the present design is given in Fig.1and the photograph of the arrangement is shown in Fig.2 The figure gives the details of various sensors, interfacing modules etc.

2.1 ARM Processor

The ARM processor is the core of the pollution monitoring system. The ARM processor LPC2378 is a high performance, low power device used widely for wireless embedded systems. The LPC2378 (Philips) ARM processor is based on a 16-bit/32-bit ARM**7** TDMI-S CPU with real-time emulation that combines the Microcontroller with 512 kB of embedded high-speed Flash memory.

2.2 Wireless Network Module

ZigBee technology is known by its very low power consumption, which in combination with low power sensor circuits comprises a system that can operate for a long period of time. By using the ultra low power MSP430 microcontroller and the CC2480 ZigBee coprocessor, it is possible to achieve several years of operation using common off-the-shelf batteries. The ZigBee module ez430-RF2480 by Texas instruments is used. This is a complete wireless development tool that includes the ultra low power microcontroller MSP430 and the low power transceiver CC2480. It operates in the 2-4 GHz industrial scientific medical (ISM) free radio frequency band with 16 channels. It provides extensive hardware support for packet handling, data buffering, burst transmissions, clear channel assessment, link quality indication and wake on radio. There are five power down modes by which the power consumption can be minimized [5].

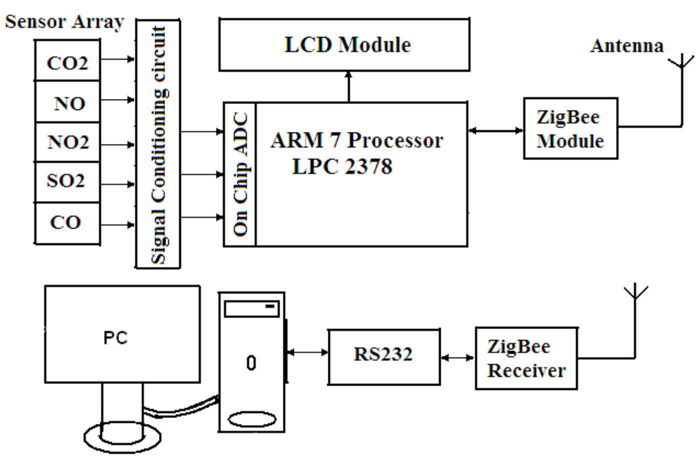

Fig.1. Block diagram of the design

2.3 Sensor Array

A simple multimode network is developed using ZigBee technology. The sensor array consists of sensors like CO sensor, CO2 sensor, VOC sensor and NOX sensors along with temperature and humidity sensors. The temperature is measured using DS 1820 sensor and resistive type humidity sensor is used. Carbon monoxide is measured using TGS 2442-CO sensor, carbon dioxide is measured using TGS 4161-CO2 sensor, the presence of volatile organic compounds such as Benzene is measured using TGS 823- VOC sensor. Nitrogen dioxide is measured using TGS 2106 sensor. The electrical response of the gas sensors is converted into voltage signals by using suitable signal conditioning circuits [6] .

2. 4 Central Server

The central server here is the personal computer (PC) with accessibility to the internet. The server (PC) is connected to the ZigBee modem using the RS232 communication standard. The data received from the ZigBee receiver is stored and displayed in the PC. A graphical user interface is developed, for the continuous analysis of the data. The data displayed on the internet will help to check the real-time air pollutants level. For this a normal browser on any PC can be used.

3. CONCLUSION

A wireless real time air pollution monitoring system is designed using the ARM**7** processor to measures the levels of various air pollutants. The measurements are made over a period of nearly two months of time continuously. Before actually starting the measurements all the sensors were properly calibrated using the procedures mentioned in the literature [7]. To study the performance of the system, the readings are taken first at the lab environment. As the performance of the sensors vary depending on the temperature and humidity, these two measurements are also made using the digital temperature sensor DS1340 and a humidity sensor.

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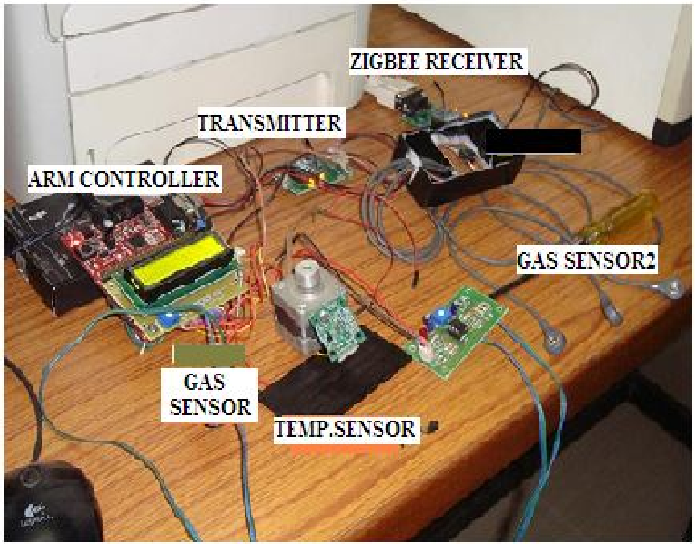

Fig.2. Photo graph showing the experimental arrangement

Low power consumption is an important criterion in the wireless sensor networks. The power consumption measurement is considered only for the end devices as the coordinator is constantly powered at the base station. Due to the measurement, the end device is configured in timer sleep mode condition. The mode is configured to wake up at every 30 minutes intervals for just 100ms to send the data to the base station. For the remaining time, the end device is in sleep mode.

The data is displayed on the monitor using the graphical user interface (GUI) and efforts are made to transfer the data to remote places using internet connectivity available.

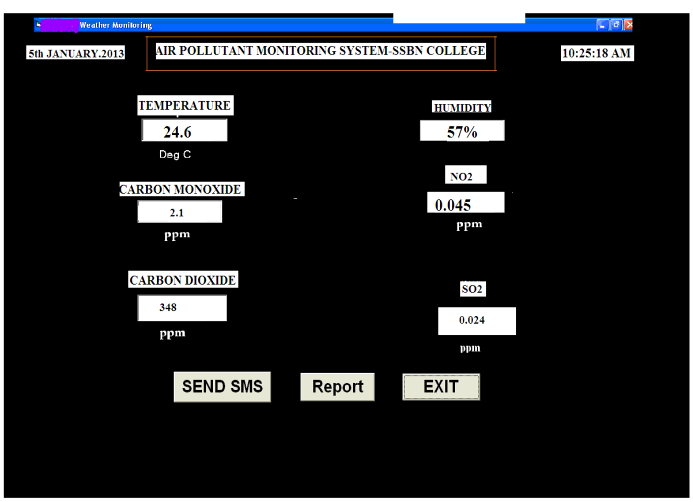

Fig.3. A snap shot showing the GUI developed in the work.

The snapshot of the GUI developed using the Visual basic software is shown in Fig.3.This GUI displays the date ,time and name of the gas and its concentration level in ppm . From the graphical user interface (GUI) observations, it is observed that within our college premises , the CO, CO_2, , etc..levels are well within the normal values, of the order of 2.1 ppm, 348 ppm respectively. Where as the SO_2 levels are of the order of 0.024 ppm and NO2 is of the order of 0.045ppm. To observe the maximum variation we arranged the system in our chemistry laboratory and conducted some carbonate experiments. Interestingly the CO levels have increased to 4.1 ppm. Similarly when the system is kept near the exhaust pipe of our four wheeler the CO levels have increased as high as 5 ppm. Similarly to study the performance of CO_2 sensor a simple test tube experiment is performed with calcium carbonate. The readings of the CO2 sensor increased as high as 2500 ppm. Similar observations were made for NO_2 and SO_2 gas sensors in our chemistry laboratory. They are found to be 0.13 ppm and 0.09 ppm respectively. To get the advantage of this embedded system, the system is tested in the industrial plant area for about six hours for two days. The levels of CO2, NO2 and SO2 are found to vary according to the reported values in the literature. As the system also contains the temperature and humidity sensors, it is found that the drift in the sensor performance with Humidity and temperature is not more than 5 % in all the sensors. Some of these results are also cross-checked with our earlier design and also those of the standard data logger Davis Vantage Vue weather station[8] . These results are found to be well within 10 % variation. The observation of the results also indicates that no gas sensor is 100 % selective to a single gas, but produces a strong signal to the corresponding gas. 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[9]. But they also suffer from lack of selectivity and sensitivity as well as higher temperatures required for use (300–500 ºC). This problem is very well tackled by developing conducting polymers in the form of thin films, blends, or nano composites. have been developed.

Another important objective behind this work is also to develop a low power embedded design ,which is successfully achieved.In the design two aspects are considered seriously. One is ,using the ZigBee module which consumes very less power during its operation .Actually this ZigBee module ez430-RF2480 by Texas instruments is meant for battery operated devices. The second aspect is the ARM processor, which is also a low power device. The ARM architecture can work in four power down modes , which makes it more suitable for the kind of applications mentioned above[10].

4. FUTURE SCOPE

In order to make the present design more realistic, in the sense more friendly user with low power ,the authors are planning to use the MSP430 series microcontroller , from Texas Instruments ,which is considered as the lowest power consuming device. Also ,by replacing the semiconductor sensors ,it is possible to use nano sensors, so that the solar power based system design can be made possible. The objective would be to design a fast, low power and real time embedded system which can be used in environmental monitoring systems and bio-medical applications etc.

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