Energy Efficient Environment Monitoring System Based on the IEEE 802.15.4 Standard for Low Cost Requirements

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***Abstract*—Power consumption, portability, and system cost are important parameters in designing pervasive measurement systems. With these parameters in mind, wireless environment monitoring system with a capability to monitor greenhouse gases, such as CO, CO_2, SO_X, NO_X, O_2 with environmental parameter is developed. In order to achieve the target design goals the communication module, the wireless smart transducer interface module (WSTIM) and wireless network capable application processor module (WNCAP) were developed based on the IEEE802.15.4, IEEE1451.2 and IEEE1451.1 standards, respectively. The low cost and energy efficient gas sensing modules were successfully developed with improved tolerance to EMF/RFI noise. We defined re-calibration of the system at time intervals to ensure that the desired accuracy in maintained. This paper presents the undertaken design detailing solutions to issues raised in previous research.**

***Index Terms*—smart sensor, smart transducer interface module, network capable application processor, IEEE802.15.4 standard, electrochemical gas sensor array.**

I. INTRODUCTION

In recent studies, global warming refers to the increase in mean air temperature in troposphere. It is frequently influenced by increasing concentration of greenhouse gases (GHGs) in the earth's troposphere. In fact, global warming is one of the major causes of climate change [1]. In the last century, according to United States Environmental Protection Agency (USEPA), climatic change occurred in terms of change in temperature, precipitation and wind patterns. However, in last century average temperature of earth is increased by 1.4^o F, and in next hundred years, it is projected to rise from 2.0^o F to 11.5^o F. Also latest IPCC draft report says that GHG emissions are responsible for rise in global temperatures leading to change climate and weather patterns [2]. This leads to extreme weather events such as flash floods, drought and severe heat waves. Moreover, the oceans and glaciers have also experienced some big changes such as warming of ocean resulting in increase the sea level and decrease in ph level (acidic) [3]. This has affected human health and resulted in drastic increase in the cases of asthma, coronary artery disease, lung cancer, chronic bronchitis, chronic pulmonary disease, and pneumonia [4]. We may note that, major greenhouse pollutants include CO_2, CO, NO_X, SO_X, volatile organic compounds (VOCs), lead aerosol and suspended particulate matter (SPM).

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Most greenhouse gases emitted from increasing industrialization, agricultural imbalances, burning fossil fuels, de-forestation, household energy use, veld fires, etc. [5]. Recent research shows that, the greenhouse gas emission reduction and its mitigation is a critical issue for earth's sustainability [6]. Effective reduction and mitigation of greenhouse gases requires a system for continuous and precise estimation of constituent gas levels. In view of continually growing sources of greenhouse gas emission, these systems should have the adaptability and ability to measure the concentration of greenhouse gases with a minimum response time and a high precession [7]-[13].

In recent years, wireless sensor networks/actuators and data harvesting technology have played an important role in the area of environment monitoring. Basically, environment monitoring systems consist of smart nodes, coordinator with PC, and some kind of actuators [11].

Postolache *et al.* [7] present a metal-oxide semiconductor (MOX) gas sensor array based WiFi network for the measurement of air quality and also explained the data processing and casting on the web. Jelicic *et al.* [12] present a PIR (pyro electric infrared) and MOX sensors based adaptive WSN model for the measurement of built air quality and also explained the network, sensor, and node level power consumption reduction techniques. Choi *et al.* [14] present a design of IEEE802.15.4 standard based gas sensor system for the monitoring of air pollution. They are focused on various themes in the design of air pollution monitoring system such as power, gas sensor operation mode, and the miniature size of the on-board processing sensor array. Chen *et al.* [15] developed a portable cell phone operated hybrid sensor for monitoring of outdoor volatile organic compounds. They combine the selective pre-concentration, separation, and tuning fork based detection principles into a single integrated wireless device. Yang *et al.* [16] developed a wireless sensor network based remote online CO_2 concentration monitoring system. They include the GPS (global positioning system) to provide the localization and time service information and an SD card to cache the real time monitoring data. Lin *et al.* [17] present a WSN based diversified model for environment monitoring and they are focused on expenditure of mobile communication, stability of data transportation, power consumption, and heterogeneity of sensor signals. Kim *et al.* [18] present a Bluetooth wireless technology based system for the control of irrigation parameter and equipment's in the remote area and they also explained the plug and play low cost communication module. Ekuakille *et al.* [19] present a predicting cognitive approach for volatile organic compound concentration measurements based on sensor networks and also used the semiconductor sensor. Yan *et al.* [20] present a design of an energy-aware sensor node and they are focused on power reduction technique on network level and node level.

However, the real-world application of the proposed system has not been implemented yet. The present systems for measurement of air quality grieve from numerous disadvantages and thus modifications are being persistently recommended. These issues entail power consumption, high platform costs, appropriate calibration and validation of gas sensors, improved accuracy, prototype models that are feasible to expand for a variety of sensor specifications, easy to operate, portability, automatic storage, real time display, EMI/RFI Noise, continuous wireless transmission and most importantly, the issue of energy efficient storage data structures. Another important issue is that in the metal-oxide semiconductor (MOX) sensor should be heated in a minimum time and also should be defined and only when this information is acquired, can the sampling rate that satisfies both low reaction time and long network duration can be chosen and configured for the gas sensors. When designing energy-efficient, low cost, portable, automatic data storage, a multidisciplinary approach is necessary.

The literature also shows that despite some attractive solutions; very few are implemented and tested in real-world establishing the existence of a gap between theory and real world application at scientifically accepted precession level.

In this paper energy efficient wireless environment monitoring system with a capability to monitor a wide range of greenhouse gases, such as CO, CO_2, SO_X, NO_X, O_2 with environmental parameter in compliance with IEEE802.15.4, IEEE1451.2, and IEEE1451.1 standards is presented. It has various advanced features such as low power consumption, easy to operate, fast response time, portability, and low cost with scientifically acceptable accuracy.

II. Developed Wireless Environment Monitoring System

Wireless environment monitoring (WEM) system is an on-line data recording and measurement embedded device which is mainly able to perform the measurements of air quality [9], [10]. Fig. 1 depicts the block diagram of the WEM system. The wireless transducer interface module (WSTIM) is linked to wireless network capable application processor (WNCAP) through zigbee communication. The developed WEM system can be used of detecting the concentration level of greenhouse gases such as SO_2, NO_2, CO, CO_2, O_2 with environmental parameter (temp. and humidity). The sensors output are processed through signal conditioning circuit and the integrated signals are connected to the inbuilt ADCs channel of the processor. After processing and integration, the sensors results are sent to a network capable application processor (NCAP) PC through zigbee module and are also saved in micro memory card (MMC) according to transducer electronic data sheet. The results are displayed on the graphical user interface (GUI) running on a PC. The mentioned design of WEM system is a self-contained unit which makes it relatively easy to add extra sensor nodes.

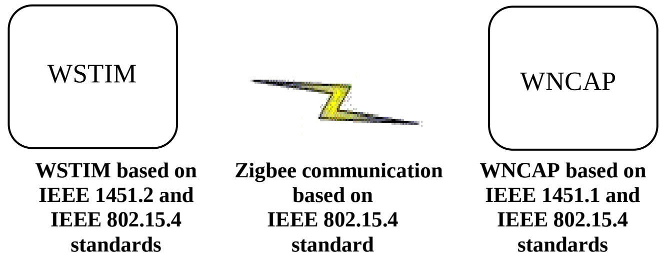


Fig. 1. Block diagram of WEM system.

III. Implementation of WSTIM

A wireless smart transducer interface modules (WSTIMs) or wireless sensor nodes consist of several components such as sensor with signal processing circuit, a power supply unit, memory, and a transceiver unit [21]. The wireless sensor node is designed based on the IEEE802.15.4 and IEEE1451.2 standards and an array of electrochemical sensors are used [22]-[24]. The developed wireless sensor module is capable of communicating with NCAP through zigbee, handling the actuators interface, and supporting transducer interface electronic data sheet (TEDS). The developed seven sensing modules are connected to the seven channels of the proposed design node and used the ADC bus. Also, three channels are free for the used in the near future. A PIC 18F4550 microcontroller is chosen to support all above functions and to support the development of the node. The power consumption of the developed sensor node in transmission (T_X) mode was measured to be 83.6241mW. The block diagram and photograph of the developed WSTIM or wireless sensor node is shown in Fig. 2 and Fig. 3 respectively. In the next section, all components are described in details:

A. Sensor Unit

The sensing unit is the main components of a wireless sensor node that differentiates it from any other embedded system with communication capabilities. The sensing unit is also a combination of several sensors known as sensor array [8]. In this section, focus is placed only on energy efficient gas sensor array.

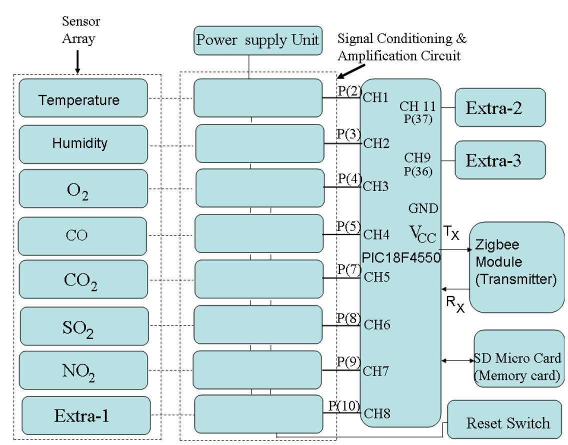


Fig. 2. Block diagram of WSTI module or wireless sensor node.

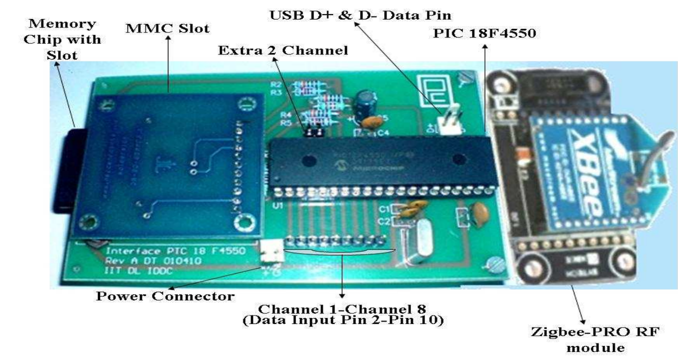


Fig. 3. Photograph of WSTI module or wireless sensor node.

A gas sensor is a device that transforms the concentration of the gas into an electric signal [9]. Generally, five technologies are used for monitoring the concentration of gases such as catalytic bead, infrared, photoionization, solid state, and electrochemical [9], [10]. Detailed information on these technologies and gas sensors, such as, advantages, disadvantages, usage, and life time is reflected in [25], [26]. We may note that the electrochemical sensor have low cost, low power consumptions, single gas detection property with high accuracy, good selectivity, no effect of the environmental parameter fluctuations, excellent repeatability, and miniature as compared to solid-state, photoionization, catalytic bead, and infrared. The major drawback of the electrochemical sensor is extremely sensitive of the EMF/RFI. In this sense, these sensors are attractive for use in different areas such as space, environment, forestry, agriculture, and automobile [27]-[29]. The sensor specifications of the used in the development of WEM system could be found in [29]-[31].

B. Sensor Signal Conditioning Circuit

Basically, the electrochemical sensors consist of two or three types of electrodes namely working electrode, counter electrode, and reference electrode [25]. The working electrode is a sensing part of the sensor and the counter electrode balances the chemical reaction of the working electrode. The reference electrode is used only when the sensor is ready to be used or removed to storage, otherwise are required a few hours of the sensor to stabilize. When the gas comes in contact with the working electrode; the reaction will start either a reduction or an oxidation mechanism and produce the current between the counter electrodes and working electrodes which is measured through the signal processing. The magnitude of this measuring current is interrelated to the concentration of the measured gas. The detailed information of the working principle and basic theory of sensor signal conditioning with linearization, signal conversion, concept of loading, filtering and impedance matching of the electrochemical sensor could be found in [25]. The operation of an electrochemical sensor to get a usable electrical output relative to concentration of the gas sensors requires a potentiostatic circuit. The developed signal processing circuit or potentiostatic circuit is divided into the four parts namely a current measuring circuit, a control circuit, amplification circuit and a stabilizing circuit. The efficiency of the signal processing circuit is determined by the characteristics of the amplifier. We have selected the ultra-low input bias (<5nA) and precise instrumentation amplifier to improve the circuit performance with regard to sensitivity, linearity, high and low frequency noise, high accuracy at low gas concentration, decrease the response time or settling time, and low power consumption. The correlation between gas concentration (C) and sensor output voltage (V) can be expressed as

$$C(ppm) = K \bullet V \qquad (1)$$

where K is the proportionality factor.

1) CO_2 Sensor Module

The developed CO_2 module consists of a CO_2 sensor, a measuring circuit and an amplification circuit. The CO_2 sensor has only two electrodes, namely, the reference electrode and the working electrode [29]. The concentration of CO_2 in air is measured by the developed module. In this module the amplifier AD620 is used in the measuring circuits and OP07 is used in the amplification circuit. The AD620 is a high accuracy, low drift, low offset voltage, low noise, low power consumption, gain control with single external resistor and precise instrumentation amplifier. The external resistor (R_G) is fixed at 1.0KΩ in measuring circuit giving a gain of 50.4. The gain of the measuring circuit is calculated by equation 2.

$$G = \frac{49.4K\Omega}{R_G} + 1 \qquad (2)$$

where G is the gain of the measuring circuit and is control by R_G (gain resistance) in Ω.

The operating voltage range of the developed module may be varied from ±2.0V to ±3.3V. It is operated at a fixed voltage of ±3.3V and the proportionality factor was fixed at 196.078. Finally, the output of the measuring circuit is fed to an inverting unity gain follower. The response time and power consumption of the developed sensor module were observed to be 300sec and 1.1434mW, respectively. The gas sensing range of the developed module is set from 50ppm to 800ppm. The CO_2 analogue signal conditioning schematic diagram and a photograph of the developed sensor module are shown in Fig. 4 and Fig. 5, respectively.

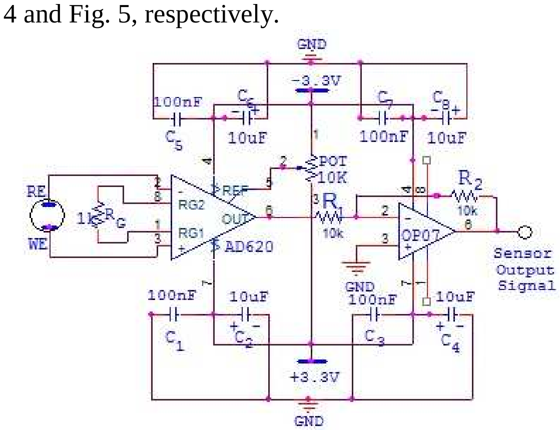


Fig. 4. Schematic diagram of CO_2 sensor module.

2) O_2 Sensor Module

The oxygen sensor has only two electrodes, namely, the positive electrode and the negative electrode. The oxygen concentration in air is proportional to the output of the sensor. The oxygen sensor output is measured by means of a circuit between the positive and negative electrodes. This circuit consists of a non-inverting amplification circuit based on OP07 with a fixed gain of 2.

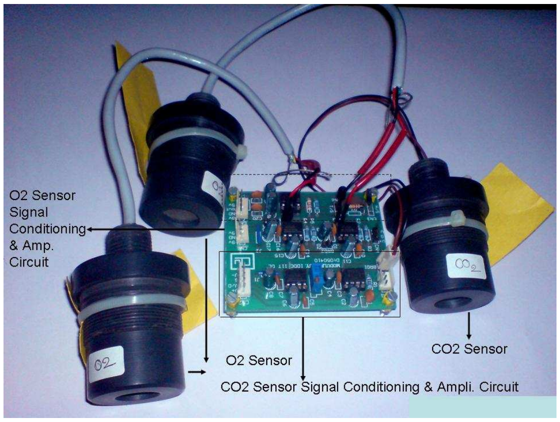


Fig. 5. Photograph of O_2 & CO_2 sensor module.

The schematic and a photograph of the developed module are shown in Fig. 6 and Fig. 5, respectively. The operating voltage range of the developed module is from ±5.0V to ±9.0V. It is operated at a fixed voltage of ±5.0V and the proportionality factor is fixed at 13.93. The response time and power consumption of the developed sensor module were observed to be 300sec and 3.6292mW, respectively. The gas sensing range of the developed module is set from 15% to 65%.

3) SO_2-D_4 Sensor Module

In this module, the amplifier LMP7721 is used in the controlling and measuring circuits while the OP07 is used in the amplification circuit. The guarding and multi-core PCB techniques are used in potentiostatic circuit layout to reduce the parasitic current. The input pins of LMP7721, are fully guarded (a guard is a low impedance conductor that surrounds an input line and its potential is raised to the input line voltage).

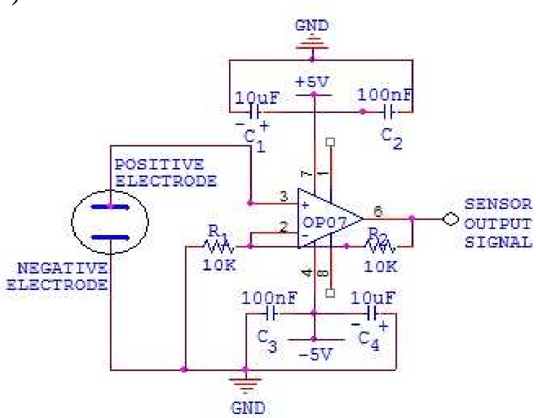


Fig. 6. Schematic diagram of O_2 sensor module.

The operating voltage range of the developed module may vary from ±2.0V to ±3.3V. It is operated in this application at fixed voltage of ±3.3V and also the proportionality factor is fixed 0.55. The load resistance (R_5) is fixed at 10.0KΩ in the measuring circuit. The output of the measuring circuit is applied to the input of the non-inverting amplifier with a fixed gain of 40. The response time and power consumption of the developed sensor module were observed to be 40sec and 0.72mW, respectively. The gas sensing range of the developed module is set from 0.04ppm to 2ppm. The schematic diagram and a photograph of the developed module are shown in Fig. 7 and Fig. 8, respectively.

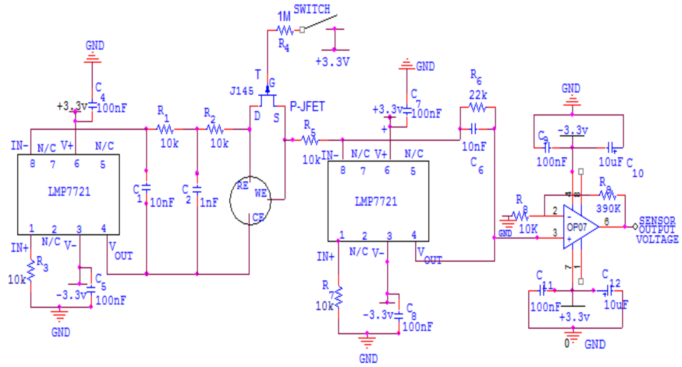


Fig. 7. Schematic diagram of SO_2-D_4 sensor module.

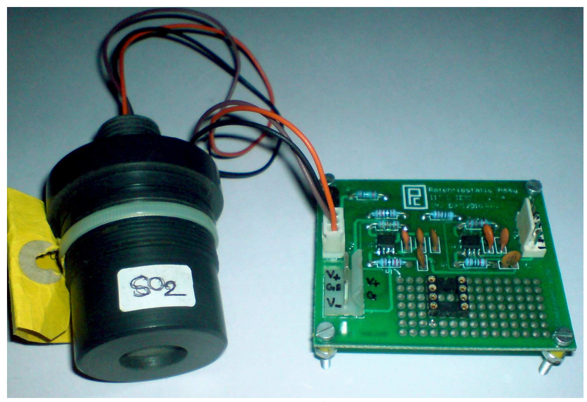


Fig. 8. Photograph of SO_2 – D_4 sensor module.

4) CO Sensor Module

The CO-CF sensor module is built in the same manner as the SO_2 - D_4 module. The load resistance (R_5) is fixed at 33.0Ω for the measuring circuit and the output of the measuring circuit is applied to the input of a non-inverting amplifier with a fixed gain of 48. The response time and power consumption of the developed sensor module were observed to be 60sec and 9.0936mW, respectively. The gas sensing range of the developed module is set from 0.5ppm to 20ppm and the proportionality factor is fixed at 4.1.

5) NO_2 Sensor Module

The NO_2 sensor module is built in the same manner as the SO_2 - D_4 module. The load resistor (R_5) is fixed at 20.0Ω for measuring circuit. The output of the measuring circuit is applied to the input of the non-inverting amplifier with a fixed gain of 33.0. The response time and power consumption of the developed sensor module were observed to be 60sec and 11.2712mW, respectively. The gas sensing range of the developed module is set from 0.01ppm to 0.5ppm and the proportionality factor is fixed at 0.1046.

6) Temperature Sensor Module

The response time and power consumption of the developed sensor module were observed to be 2sec and 1.7673mW, respectively. The temperature range of the developed sensor module is set from 15°C to 70°C.

7) Humidity Sensor Module

The response time and power consumption of the developed sensor module were observed to be 15sec and 1.0mW, respectively. The humidity range of the developed sensor module is set from 0% to 100%.

C. Noise Reduction Techniques of Gas Sensor

The major drawback of the electrochemical sensor is its extremely high sensitivity to EMI/RFI noise or interferents. The way out of the RFI/EMI or interferents problem is to use following technique for the reduction of RFI/EMI or interferents problem -

A thin metal cylinder is surrounding of the electrochemical sensor and the cylinder outer surface is connected to the ground of PCB. This cylinder is further surrounded by a thin PVC (polyvinyl chloride) cylinder enclosing the entire sensor and this PVC cylinder work as a mechanical protection. Sensors are connected to the potentiostatic circuits through shortest leads (3cm) because of the low sensor currents and low impedance. Two gas (SO_2) sensing modules using same sensors are developed with two different PCB design technologies. Minimum noise is achieved in the case of the developed multilayer circuit board which includes a good grounding. Sensor and its associated circuitry are connected through wires with good grounding and shielding in the circuit.

Circuit stability and noise reduction in the control circuit relies on R_1, R_2, C_1, and C_2 (Fig. 7). C_2 may not be necessary for control circuit. To eliminate C_2, C_1 needs to be increased between 10 to 100pF. In addition, the internal sensor capacitance and internal sensor resistance plus load resistor (R_5) establish an RC circuit. The RC circuit affects both the ***response time*** and ***rms noise***. If R_5 is high then ***noise is low*** and ***response time is slow*** or vice versa.

D. Control Cross Sensitivity or Interfering Gases

Interfering gases, often called cross sensitivity, are gases other than the target gases which will cause the cell to react. The electrochemical sensors are generally very selective to the target gases and not suffer from cross interference because in the electrochemical sensor, the chemical filters are used, these filters remove the interfering gases by adsorbing onto the chemical filter materials. And also the main advantage of the electrochemical gas sensors is its operation in the zero bias mode. But the semiconductor sensors and catalytic sensors are non specific sensors and will responds to number of gases or volatile organic compounds (gases of the same group or family). We have used the two methods to eliminate or controlling the interfering gases or cross sensitivity: applying a bias Voltage to control op amp, and Shorting the JFET. Fig. 9 represents the method of biasing of the gas sensor. It shorts the working and reference electrodes through JFET to ensure that is the same potential between working electrode and reference electrode. The JFET is active when input bias voltage through a 1MΩ resistor is applied (as shown in Fig. 7).

And also biasing should be mentioned when the instrument is switched off or if we do not use a shorting JFET.

E. Operation of the MMC

Micro memory card (MMC) is a miniature, high capacity, rewritable, storage device. Another important advantage of the MMC, MMC is support in SPI (serial peripheral interface) and operates in full duplex mode. At the present time, The MMC is used frequently in the development of the instruments, for example mobile phones, digital cameras and computers, etc [32].

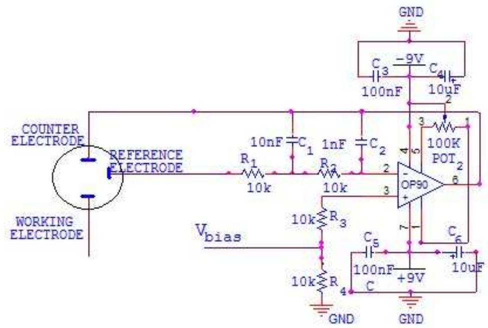


Fig. 9. Applying a bias voltage to the control op amp.

During operation in full duplex mode only six pins were used. These are two data pins work in a master-slave mode (MOSI and MISO), two power pins, chip select (CS) and serial digital bus protocol. Initially, MMC responds in SD protocol and during operations that switch in SPI mode. The SPI mode of the MMC is supported in a single block operation as well as multiple block operation. In the development of WEM system we have choose the multiple block operation. In multiple block operation, first of all, the file is created separately for each monitoring parameters viz. CO_2, CO, NO_2, SO_2, O_2, temp., and humidity and after that the writing operation is completed. Clicking on the save button of the developed WEM system will initiate storage of on-line data in the MMC according to the electronic data sheet. 1GB memory card is used in the development of WSTIM and it supports upto 32GB memory card. The used 1GB card is divided into 10 multiple blocks; of these, 8 blocks are of equal space (125MB), 44 Bytes is used register array block and unsettled space is kept blank. The 8 equal space blocks are connected to the channel 1 to 8 of the developed WSTIM. The photograph of micro-memory card (MMC) interface module is shown in Fig. 3. The power consumption of the MMC card is depends on the data transfer speed (clock rate). In SPI mode, we have used the 20MHz crystal and $F_{OSC}/16$ bit rate or clock rate is used in the Programmed. The maximum clock frequency fixed at 1.25MHz of the developed system. The typical range of the MMC card is 66mW (3.3V) -330mW (3.3V) at clock frequency 25MHz and 50MHz respectively. But in our case, we have used the clock frequency of 1.25MHz. According to the clock frequency the MMC is consumed the maximum power 16.5mW.

F. Re-calibration of the System

Calibration is the most important issue in the designing of instruments for the system reliability. Measurement instrument is required to be calibrated at a time intervals with the intent that the desired accuracy and quality level is maintained. The system calibration research area is an emerging stage for the development of WSN based instrument.

The static and dynamic chamber methods for the sensor module calibration are available. We used the static chamber method to calibrate the sensor array. They define the zero value and span of the sensor, also, they used the synthetic air and unpolluted nitrogen to calibrate the zero value of the sensor [8], [33]. We also used the factory calibrated sensors in the development of sensor module. And after integration we choose the static chamber method. The static chamber method required testing gas with known different gas concentration; adjust the pressure of the valve and flow meter so that approximately 30l/h flow into the gas inlet, after 10 minutes a stable signal appears.

First of all, we set the stand by voltage of the developed sensor module. The pure nitrogen and clean air were used to find the stand by voltage. And after that by applying a different known gas concentration and compared the results of the developed WEM system to existing systems of known gas concentration. The resulting difference or linearization error may be corrected through the R_5 signal processing circuit. Fig. 10 and Fig. 11 represent the calibration curves after integration of the sensor module. The system calibration is required in near future and then can be adjusted by following this procedure. The accuracy of the measured gases as per the well-known manufacturer's data is given in Table I.

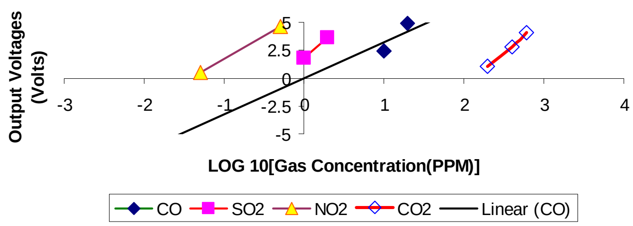


Fig. 10. Calibration curve after integration of CO, CO_2, SO_2, NO_2 sensor module.

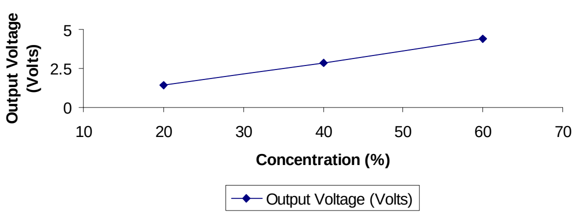


Fig. 11. Calibration curve after integration of O_2 sensor module.

G. The WSTIM Kernel – Main Control Program

The data transfer program is written in 'C' programming language according to IEEE1451.2 and IEEE802.15.4 standards [23], [24]. Detailed information on PIC 18F4550 microcontroller 'C' coding functions could be found in [22], [25]. All the functions of the developed wireless standard transducer interface module (WSTIM) is controlled by the wireless network capable application processor (WNCAP) or coordinator. The WSTIM program is developed for seven sensors and divided into three functions such as interrupt, data transport, and trigger. All these functions are supported by the WNCAP module. Each sensor module program is further divided into three slabs, first input is read, second send the data to the zigbee RF PRO S2 module and third the data is saved on the micro memory card (MMC). At power up, the microcontroller executes the initilization command of the micro-memory card (MMC) module, status registers, sensor channel data buffers and zigbee PRO-S2 module and after that it enters into a permanent loop and drives through the actions.

TABLE I
ACCURACY OF THE MEASURED GASES

Monitor GHGs	Instrument with Company Name	Accuracy
CO	IAQ-Calc™ IAQ 7545 Trak Plus	±3%
SO_2-D_4	GAXT-S-DL (BW-Technology)	±2%
CO_2	Trak Plus Q-8552 & 8554	±3%
O_2	Bacharach IAQ 2825 Analyzers	±4%
NO_2	GAXT-D (BW- Technology)	±2%
LM35CZ	HOBO H8 Temperature	±0.8%
Humidity	HOBO H8 Temperature & Humidity Data Logger	±0.7%

IV. WIRELESS COMMUNICATION

The zigbee communication is being used for the development of WEM system because zigbee is a self-configuring, long battery life, low cost, high reliability communication technology [12], [24]. Zigbee network has distinguished applications such as smart farms, military (viginet), telemedicine services, home device control and other commercial applications [21]. Real-world environment monitoring is one such application area that is attracting researchers around the world in response to global warming. The wireless communication between the wireless standard transducer interface module (WSTIM) and wireless network capable application processor (WNCAP) is achieved through a zigbee communication and XBee-PRO S2 module is selected. The XBee-PRO S2 modules are capable for transferring the data for both indoor and outdoor line of sights [34]. To begin with, we have created a network between the coordinator (WNCAP) and node (WSTIM) through X-CTU. In our system networks, there is one coordinator and several WSTI modules. However, all developed modules (coordinator and end Module) are on same PAN (private area network) ID. If the develop system is working properly, then it normally establishes a connection between the WNCAP-PC and the WSTI modules. And the communication between zigbee coordinator and NCAP is through a serial communication. Serial communication depends on the UART (universal asynchronous receiver transmitter). The RF module can work in four modes of operation namely, idle, transmit, receive, and sleep modes [12].

V. THE WNCAP MODULE

The wireless network capable application processor (WNCAP) is developed based on the IEEE1451.1 and IEEE802.15.4 standards [24], [35]. The developed WNCAP module is shown in Fig. 12. The WNCAP module is divided into two parts, the zigbee coordinator and graphical user interface (GUI). The GUI is designed in LabVIEW 9.0. It performs the all functionalities such as signal reception, visualization, and (micro memory card) MMC data storage. The data saved correspond to the fixed of the sample value and we have designed the sample ranges from 1sec to 100sec. The on-line WNCAP module front panel is shown in Fig. 13. The developed front panel has the start button, knob for setting sample interval, digital and graphical output, data save, and stop button. The front panel is designed for eight sensing modules but we have used only seven sensing modules and the last one can be used in the future. The block diagram represents the controlling and conditional structures of operations for CO sensor module is given in Fig. 14. i.e. internal oblong reprents the controlling and conditional structures of operations, and outer oblong represents the while loop. In partcular, the CO block diagram the flag 100 is set on the conditional structure i.e. flag 96 of controling structure and add of 4 (ADC4-connected to the sensor module). The other gases and environmental parameters sensor modules block diagram are the same as in Fig. 14, only difference the conditional and controlling structure parameters.

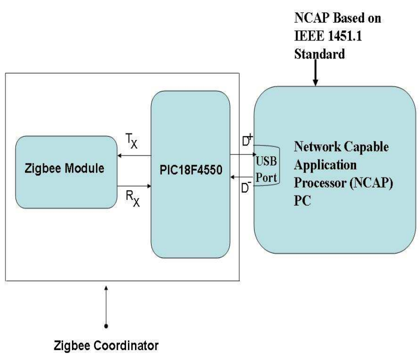


Fig. 12 Block diagram of WNCAP module.

A. *Interface between Zigbee Coordinator and NCAP PC*

An interface between zigbee RF module (receiving mode) and GUI PC based on the IEEE1451.2 and IEEE802.15.4 standards is developed [22], [24]. The IEEE1451.7 standard based USB interface between zigbee coordinator and GUI PC is developed in the WEM system. There are various advantages of the USB based interface such as reliability, hot pluggable, low power consumption, low cost, etc. Another most important advantage of the USB based interface module is that USB PC port provides the 100mA at 5V power for external use. As a result, no additional power source is needed for the zigbee coordinator. USB supports the serial data transfers in four ways, namely, interrupt transfers, control transfers, isochronous transfer, and bulk transfer [36]. In this paper, the interrupt driven transfer protocol was chosen. The LabVIEW based GUI requires driver software for the I/O communication with zigbee coordinator. In these days, many types of drivers are used for communicating to instruments. In this paper, we make use of VISA drivers. VISA is a support for serial instruments or standard application programming interface (API) for instruments I/O communications. The detailed information on the different communication drivers including VISA sub palette in LabVIEW, advantages, disadvantages can be found in [37].

VI. Results

The electrochemical sensor array based low cost and energy efficient wireless environment monitoring system (WEMS) is developed for the monitoring of the concentrations of greenhouse gases such as CO_2, CO, NO_2, SO_2, O_2, with environmental parameter (temp. and humidity). The communication module, the wireless smart transducer interface module, and wireless network capable application processor module is successfully developed based on the IEEE802.15.4, IEEE1451.2 and IEEE1451.1 standards, respectively. Because the wireless network capable application processor (WNCAP) module power does not require an external power supply, as it uses the available PC or Laptop USB slot power. The total power consumptions of the developed WEM system is depend only on the power consumed by wireless standard transducer interface module (WSTIM) and it is found to be 83.6241mW. In experiment we have used 11.1V battery which is rated 350mAh (3.88Wh).

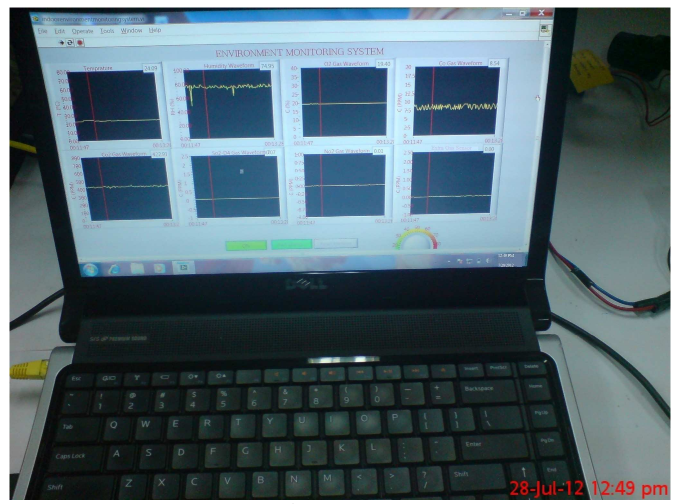


Fig. 13. Front panel of environment monitoring system.

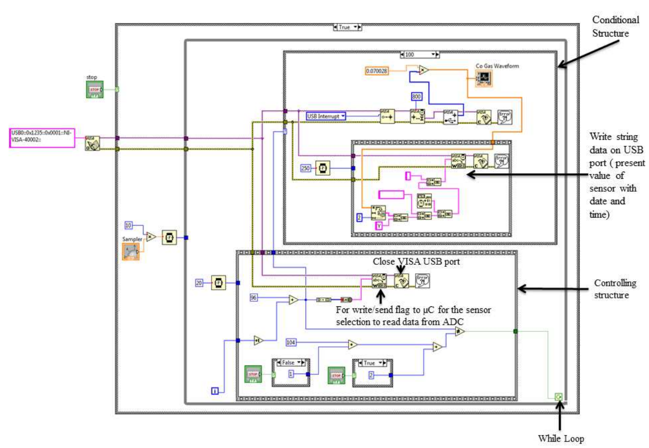


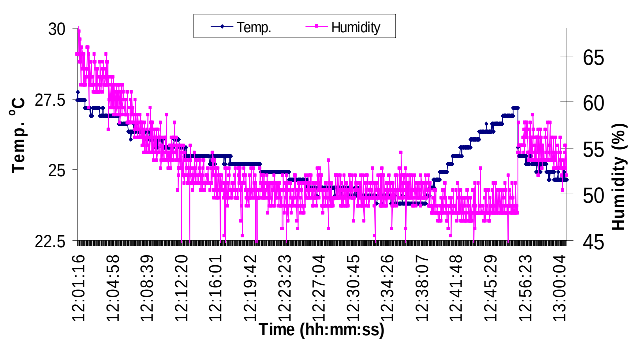
Fig. 14. CO data flow block diagram.

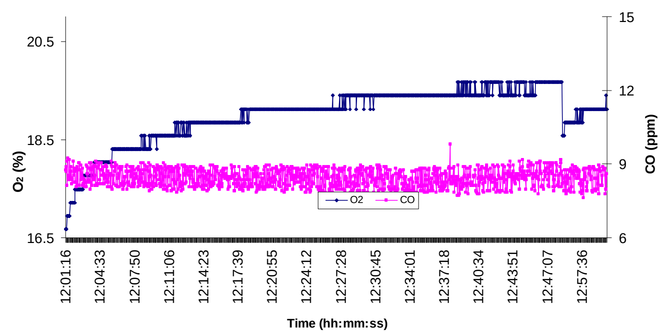
The WEM system can work for 50 hours without needing recharge. The power consumption of the WEM system is far less than the other available systems. The total cost of the developed WEM system is approximately US$600 is very less as compared to the existing system. Table II represents the comparisons of the WEM system in terms of power consumption, cost, accuracy, measured gases and measured range. In addition based on the obtained results such as accuracy and easy operation, the performance and quality of measurements of the developed system is better as compared to the existing systems.

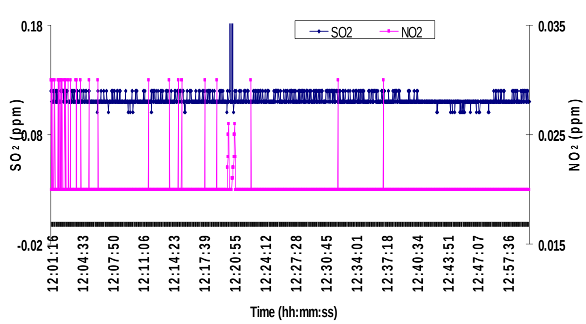
The electrochemical sensors were triumphingly used for on-line monitoring of the greenhouse gases. The usage of these sensors adds numerous benefits to a system, such as, scientifically defined accuracy, low cost, low power consumption, fast response time, etc. Gas sensing standard modules, consisting of built-in electrochemical sensors and associated signal conditioning circuits, are successfully developed and RFI/EMF noise using PVC gas sensing holder is improved. The system calibration issue is resolved into two steps: first finding the stand by voltage of the developed sensor module and after that by applying a different known gas concentration. The resulting differences or linearization error are corrected through the R_5 signal processing circuit. If the system calibration is required in the near future and then it can be adjusted through this procedure. The online data of greenhouse gases such as CO_2, CO, NO_2, SO_2, with environmental parameter sensors are recorded as shown in Fig. 15 for duration of one hour, in-situ.

TABLE II
AVAILABLE ENVIRONMENT MONITORING SYSTEM DEVELOPED BY WELL- KNOWN GROUPS

System Or Refer.	Measured Gases	Power Consumption	Prices (US$)	Measured Range	Accuracy
WGM, RAE Systems Inc., San- Jose, USA	O_2, CO, SO_2, NO_2, VOC	T_X= 535mA@7.4V R_X =310mA@7.4V Idle =85mA@7.4V	5000	O_2 = 0-30%; CO = 0-500ppm SO_2 = 0-20ppm; NO_2 = 0-20ppm	±20%
HOBOZW008 &ZWRCVR	Temp., CO_2	Radio power 1.6mW	900	4-20MA for every module	±1.1544mV plus 2%
Drager X-Zone 5000, Germany	O_2, CO, NO_2, SO_2, CO_2	T_X =1000mA@6V R_X = 310mA@6V Idle = 40mA@6V	6000	O_2 = 0-20%; CO = 0-2000ppm SO_2 = 0-100ppm; NO_2 = 0-50ppm; CO_2=0-5%vol	O_2 = ±0.1%; CO = ±2ppm; SO_2 = ±0.1ppm; NO_2 = ±0.1ppm; CO_2=0.1%vol.
24	VOC, CO_2, PM	120mA@12V	…	10-1000ppm, 0-2000ppm, 8,000/28 ml	CO_2 = ±5.0%, PM = 1 µm
22	CO & VOC	Gas Sensors (ON) + T_X = 58.02mA@3V; Gas Sensors (ON) + Idle = 55.80mA@3V	…	…	….
Network Research Lab 2243 Kemper Hall Davis	Temp., Pressure, acoustic	T_X = 300mW; R_X = 200mW;Idle= 40mW; Sleep < 0.8mW	3000	….	±10%
HOBO U30 Remote Monitoring system	CO, CO_2, O_2, T &RH	……	3000	CO_2 =0-2500, & 0-4000; Temp.= -20°C - 70°C; RH=1%-95%	CO_2 = 5% (@±50ppm), Temp. = ±0.21%;RH=±2.5%







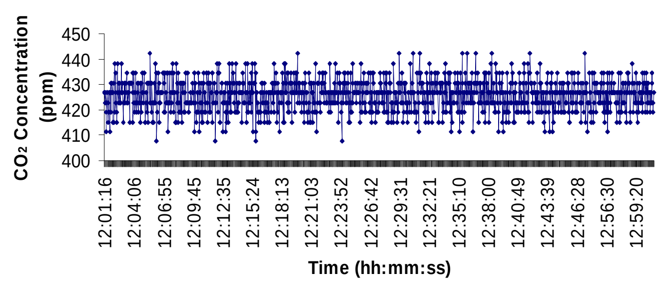


Fig. 15. Measurement of the online greenhouse gases CO, CO_2, SO_2, NO_2, O_2 with environmental parameter.

VII. CONCLUSIONS

In this paper, we present a low cost, and energy efficient prototype of a wireless environment monitoring system. The prototype system consists of the communication module, the wireless smart transducer interface, and wireless network capable application processor modules. These modules are successfully developed based on the IEEE802.15.4, IEEE1451.2 and IEEE1451.1 standards. This prototype system is tested for the monitoring of greenhouse gases and environmental parameter in-situ and open environment.

In the signal processing circuits, the PVC holder based sensors, low (<5nA) input bias current amplifiers, multicore PCB, and calibration switch are used for the requirement of low power consumption, low cost, ease of operation, low EMI/RFI noise, and miniaturization. The total power consumption of the developed WEM system is found to be 83.6241mW. The power consumption and cost of the developed WEM system is far less than the existing systems. In addition the performance and quality of measurements of the developed system is better as compared to the existing systems.

For further study, the RF interference in the 2.4 GHz can be alleviated by considering other frequency bands such as the 433 MHz which can be achieved through the new DASH7 [38] communication technology. This technology presents better penetration through walls, which is important for indoor applications. In addition, the WSN will be explored in the area of green building such as built environment monitoring management, elder carrying, and harvesting power management.

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