Design and Development of Wireless Sensor Node

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***Abstract*— This paper presents design and development of intelligent sensor node for environmental monitoring. The node is equipped with multimode sensors for sensing different environmental parameters, the node can sense four different environmental parameters, light, temperature, humidity, and three different types of gases. The node has half duplex wireless communication feature which is achieved by using an IEEE 802.15.4 standard compliant transceiver. Here we have deployed various intelligent protocols to achieve intelligent power management and precision sensing. The node comes with various error detection and correction capability which enhanced the performance of the node. Two different types of methodology are used to prove the intelligence of the node. The node is equipped with multiple sensors like gas, temperature, and humidity, light. A Special remote system enables user to wirelessly select the particular sensor which provides high wireless hardware flexibility. More priority is given to power consumption and sensing efficiency which is achieved by incorporating various smart tasking and power management protocol. All sensed data are digitized and processed by the internal analog to digital converter (ADC) of a Programmable interface controller (PIC) microcontroller and wirelessly transmitted to the base station for data acquisition and statistical analysis.**

Keywords- Sensor node;intelligent protocol; multimode sensors; gas sensors,smart tasking;power management protocol

I. INTRODUCTION

One of the efficient methods of measuring environmental parameter is by using a wireless sensor node. The Wireless sensor network (WSN). A typical sensor node consists of multiple sensors processed and controlled by a centralized processing unit. A sensor may perform various types of task depending on node resource available like node battery power, node sensor and limited onboard processing capabilities.

A number of research works have been published in last few years in the application of environmental sensing using WSN. For example [1] describes the development of smart sensor network for hazardous gas monitoring by using three types of gas sensors. Sensorscope [2] and CitySense [3] are examples of large-scale wireless environmental monitoring systems. There are many nodes which have been used in laboratory experiments but are not suitable for real time application due to parameter like power consumption, sensing efficiency and external parameter dependency such as temperature and humidity dependency of the sensor. Some other platforms are also developed by considering the energy-intensively. [4]Describes monitoring of irritant/toxic gases by using colorimetric chemical sensing film coated PMMA window aperture directly above the light sensor. [5] Describes implementation of intelligent protocol such as intelligent sensor trigger, smart sensor switching by which the life time of the node can be enhanced, but proposed system did not consider flexibility in the radio frequency (RF) power. Some years ago Crossbow [6] began to market the MEP-SYS kit for monitoring environmental parameters. This product, comprising two types of nodes, can be used to monitor ambient temperature, relative humidity, radiation and barometric pressure. Crossbow offers manufacturing eKo-kit, which offers greatly improved robustness as compared to earlier products. It incorporates a small solar panel, and most importantly, it can be linked to up to four sensors, either Crossbow or other makes, by 2 or 3 wire interfaces. But it no charge controller or energy metering capability. N-smarts [7] is a GPS-enabled cell phone-based or car-mounted citywide environmental data acquisition system. Its sensor module consists of carbon dioxide, carbon monoxide, three-axis accelerometer, and temperature sensors. The scheme focused on data collection and presentation, but did not consider issues like the characteristics of the gas sensors and energy management. In Section 2 we presented detailed discussion on various design aspect of sensor node for environmental monitoring in terms of hardware. Section 3 describes detailed aspects of hardware selection of the node. In Section 4 we have shown the construction details of the node. Section 5 describes the experimentation details. Section 6 discusses smart tasking and processing. Section 7 we conclude the paper.

II. DESIGN ASPECTS OF SENSOR NODE

There are many important design aspects of a sensor node, especially when the application is environmental monitoring. The important parameters which should be considered while designing a sensor node are resource such as battery power, onboard limited processing capability, and node intelligence. So the node should be designed in such a way that it consumes minimum power to extend the life time and to use minimum hardware which makes the node more compact and reduces cost and also the node should be equipped with various smart protocols to perform various error detection and correction. A typical node is equipped with multiple sensors, battery, processing unit and a wireless communication module for transmitting and receiving various sensed signals and commands, commands are special instructions given by the base station to sensor node. Sensors provide different types of output signal it may be analog, quasi digital or digital o/p. In some chemical gas sensors it is essential to supply high current to the heater coil of the gas sensor. So the signal conditioning circuit should be smart enough to drive and process variety of signals with minimum hardware. The sensor nodes are generally placed in remote areas for e.g. in hilly areas, forests, etc. It is very difficult to maintain or calibrate these sensors in these areas where accessibility is a major problem. To avoid this, we require an intelligent system which will enable the sensor to automatically detect its errors, transmit this error information to the base station, as well as correct this error if possible. There should also be a flexibility by which the base station can control various aspects like switching ON/OFF of the nodes by sending command signals and also it can select the proper sensor. By keeping these parameters into consideration, we have designed the sensor node which will be discussed in the following section.

III. HARDWARE SELECTION

To design a sensor node the first an important work is hardware selection, the hardware components should be chosen carefully to obtain high efficiency with minimum hardware and cost.

A. Processing unit selection

The node has been developed with a minimal number of components. This is due to the low power consumption requirement and in part to the need to keep the node size and manufacturing cost to a minimum. The core of the platform is a PIC18F2550 ultra-low power microcontroller (μc) from Microchip. This architecture, combined with eight power management modes, is optimized to achieve extended battery life in portable measurement applications. This device provides "Alternating Run" Modes by clocking the controller from the Timer1 source or the internal oscillator block, power consumption during code execution can be reduced by as much as 90%. It also provides additional features for robust operations like fail safe clock monitor which constantly monitors the main clock source against a reference signal provided by the internal oscillator. If a clock failure occurs, the controller is switched to the internal oscillator block, allowing for continued low-speed operation or a safe application shutdown. It writes to their own program memory spaces under internal software control. By using a boot loader routine, located in the protected Boot Block at the top of program memory, it becomes possible to create an application that can update itself in the field. This module incorporates 10-bit Analog to Digital Converter (ADC) converter which has programmable acquisition time, allowing for a channel to be selected and a conversion to be initiated, without waiting for a sampling period and thus, reducing code overhead. When the microcontroller is using the internal oscillator block, the enhanced universal asynchronies receiver/transmitter (EUSART) provides stable operation for applications that talk to the outside world without using an external crystal.

B. Wireless communication

For wireless communication is achieved by using Chipcon CC2500 RF transceiver module. The circuit combines very low power and efficient operation with support for IEEE 802.15.4. 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. The radio module performs Automatic Reception(Rx) Polling using low power RC oscillator, with 460 Hz filter bandwidth and 250 kbps data rate, PLL calibration every 4^{th} wakeup. We have designed the protocol to vary the polling period which depends upon the various conditions. The output transmitting power of the module can be controlled ranging from 1db (Highest) to -30db (Lowest). There are five power down modes by which the power consumption can be minimized. It has a high performance easy to design an efficient product.

C. Sensors selection

The node is incorporated by six sensors which measures four different types of environmental parameters- temperature, humidity, light intensity and gasses. These sensors are Temperature sensor DS 18S20, Resistive type Humidity sensor, Light to Frequency converter TSL235R, air contaminants sensor TGS 2600, Natural Gas (methane) sensor MQ-4, Carbon Monoxide sensor MQ-7. The TSl235R light-to-frequency converter is a three pin integrated circuit which combines a silicon photodiode and a current-to-frequency converter on a single monolithic CMOS integrated circuit. Output is a square wave (50% duty cycle) with frequency directly proportional to light intensity (irradiance-E_e) on the photodiode. The digital output allows direct interface to a microcontroller or other logic circuitry. The device has been temperature compensated for the ultraviolet-to-visible light range of 320 nm to 700 nm and responds over the light range of 320 nm to 1050 nm. Higher resolution and accuracy is obtained using frequency measurement. Frequency measurement provides the additional benefit of averaging out random or high frequency variations (jitter) resulting from noise in the light signal. Resolution is limited mainly by available counter registers and allowable measurement time. Frequency measurement is well suited for slowly varying or constant light levels and for reading average light levels over short periods of time. Integrating the accumulation of pulses over a very long period of time, can be used to measure exposure (the amount of light present in an area over a given time period). Under test condition of $E_e = 430$ $\mu W/cm^2$ for the monochrome light of wavelength $\lambda_p = 635$ nm, the output frequency varies from 200 kHz to 300 kHz for different intensity of light. The output from pin 3 is connected to the timer of the µc and by measuring the period with reference to the fast clock of the µc the frequency is calculated which is calibrated to the determine the intensity of light. The DS18S20 Digital Thermometer provides 9–bit centigrade temperature measurements and has an alarm function with nonvolatile user-programmable upper and lower trigger points. The DS18S20 communicates over a 1-wire bus that by definition requires only one data line (and ground) for communication with the µc. Each DS18S20 has a unique 64-bit serial code, which allows multiple DS18S20s to function on the same 1-Wire bus, thus it is simple to use one pin of µc to control many DS18S20s distributed over a large area. Another feature of the DS18S20 is the ability to operate without an external power supply. Power is instead supplied through the 1-Wire pull up resistor via the data input/output pin when the bus is high. The high bus signal also charges an internal capacitor (CPP), which then supplies power to the device when the bus is low. This method of deriving power from the 1-Wire bus is referred to as "parasite power." As an alternative, the DS18S20 may also be powered by an external supply on VDD. The TGS2600 has high sensitivity to low concentration of gases air contaminants such as hydrogen and carbon monoxide which exist in cigarette smoke. The sensor can detect hydrogen at several parts per million (ppm). The sensing element is comprised of a metal oxide semiconductor layer formed on an alumina substrate of a sensing chip together with an integrated heater. In the presence of a detectable gas, the sensor's conductivity increases depending on the gas concentration in the air. A simple electrical circuit can convert the change in conductivity to an output signal which corresponds to gas concentration. The sensor MQ-7 has high sensitivity to carbon monoxide. The detecting range of this sensor is 20 ppm - 2000 ppm of carbon monoxide. The resistivity of this sensor depends on the concentration of the gas. Its resistance varies from 2k-20k ohms. One special property of this sensor is that the heater coil is given pulsating power supply. For 60 sec the heater is given 5 volt supply and for the next 90 sec it is given 1.4 volt supply. Due to this property the power consumption of the node reduces. The output signal corresponding to the pulsating heater voltage (VH) is shown in the fig.1. The sensor MQ-4 has high sensitivity to Natural Gas and Methane (CH_4) and has small sensitivity to alcohol and smoke. The detecting concentration of this sensor is from 200 ppm – 10000 ppm for Natural gas and Methane. The sensor resistance varies from 10k – 60k ohms. These sensors (MQ-4 and MQ-7) are composed by micro Al_2O_3 ceramic tube, Tin Dioxide (SnO_2) sensitive layer, measuring electrode and heater which are fixed into a crust made by plastic and stainless steel net. The heater provides necessary work conditions for work of sensitive components. The humidity sensor module consists of resistive humidity sensor, whose sensor resistance changes according to the relative humidity (RH). The module provides analog output voltage. The output voltage varies from 1.35 volt to 2.75 volt for 25 to 90 percent RH respectively.

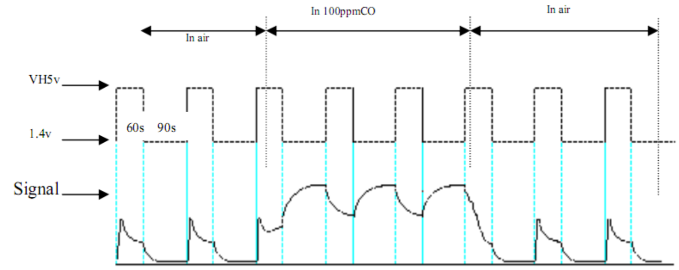

Fig1: Output signal response due to pulsating VH

IV. CONSTRUCTION

A typical wireless sensor node equipped with temperature, humidity, light, and three different types of gas sensors is shown in (fig: 2). the detail designed node architecture (fig: 3) consists of power management unit, processing, signal conditioning , and wireless communication.

Fig 2: Wireless Sensor node

A. *Power supply and power management*

The node have dual power source, a 3.7V, 2000 mAh lithium polymer battery and a solar panel which provides 250mA of current. The solar panel charges battery as well as provides power to the node in presence of solar source and in its absence node is powered by the battery. The energy meter integrated circuit (IC) MCP 3906 is used to measure the incoming current from the solar panel and also the current consumed by the node. This hardware feature is used to implement intelligent power management protocols of the node. MCP73841 charge controller IC is managing the charging mechanism. Two DC-to-DC converters are used to generate 3.5 volt and 5 volt supply which drives various components of the node.

B. Processing and Signal Conditioning

The resistive sensor outputs (TGS2600, MQ-4, MQ-7) are converted to analog voltage by using voltage divider network followed by high impedance amplifier, this analog voltage is digitized and processed by centralized PIC18F2550 µc. The internal 10-bit-ADC converts analog signal to digital form. The heater supply voltage for the gas sensors is controlled by a switching circuit by which helps to trigger the appropriate sensor. The light intensity is obtained by measuring the output frequency from light sensor TSL235R by comparing its period with reference to fast clock of the µc. The humidity sensor output is connected to a channel5 of internal ADC of µc. The communication between the temperature sensor DS18S20 and µc is achieved by sending various signal commands. The sensor gives 9-bit output in centigrade.

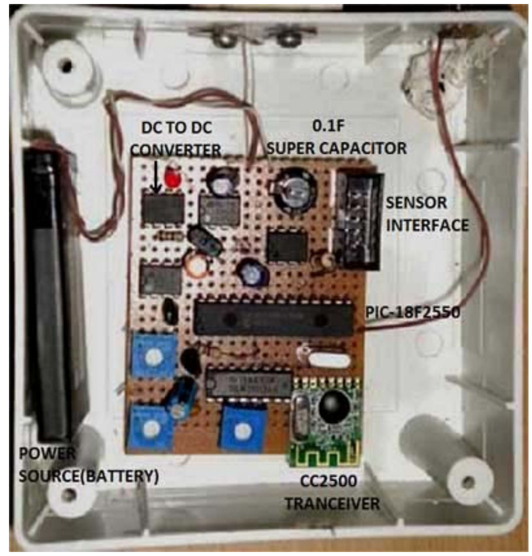

Fig 3: Internal circuitry of the node

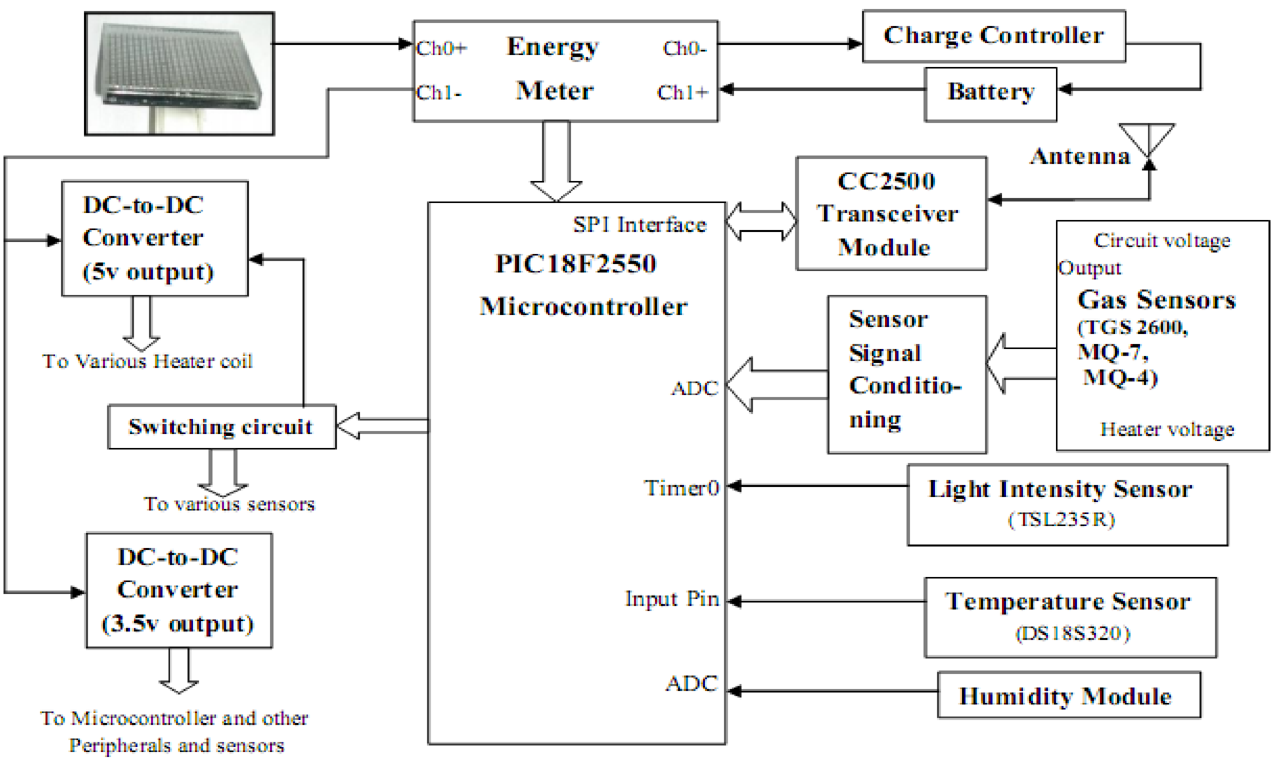

Fig 4: Internal architecture

C. Wireless Communication

The wireless transceiver CC2500 module is connected to the port D of the µc and SPI protocol has been used for communication. A special protocol is developed to adjust the transmitting power level depending on the environmental condition.

V. EXPERIMENT

We have performed various lab based and open environment experiments to validate the proposed hardware design. The node is deployed in 100 meter distance from the fusion center (fig:10), The base station is consists of a personal computer and a wireless acquisition unit, all data are stored in the computer memory for offline statistical analysis. The experiments have been carried out in different phases. In first phase we have perform sensor pre heating and circuit heating in clean air for a period of 72 hours. It is an essential step which should be performed when sensors are being used for first time. In the second phase we have calibrated the sensor response. (Fig:5) shows comparison curves between the response of node temperature sensor and reference thermometer output.

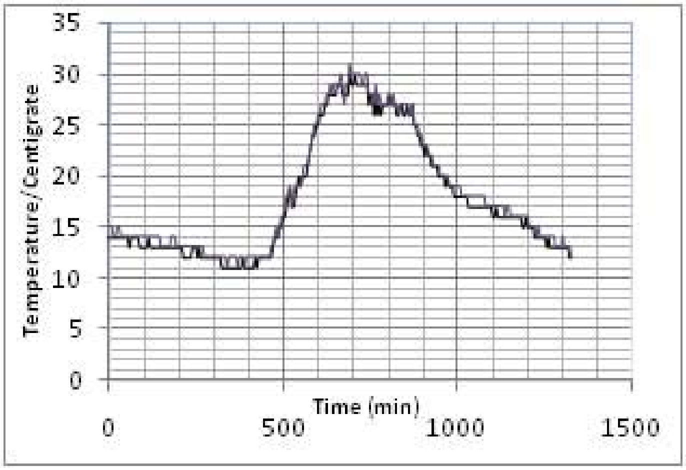

Fig 5: Temperature measurement curve

Component	*Current consumption*
MCU idle:CPU off Peripherals on	5.8 µA
Sleep mode	0.1 µA
Radio transmit at 0db output power	21.2 mA
Radio receive at 0db output power	13.3 mA
Temperature sensor DS18S20	4mA
Light sensor TSL235R	3mA
Humidity sensor module	2mA
Carbon Monoxide sensor MQ-4	80mA
Methane CNG Gas Sensor MQ-7	155mA
Hydrogen and Carbon Monoxide sensor TGS2600	65mA

Fig 7: Power consumption chart

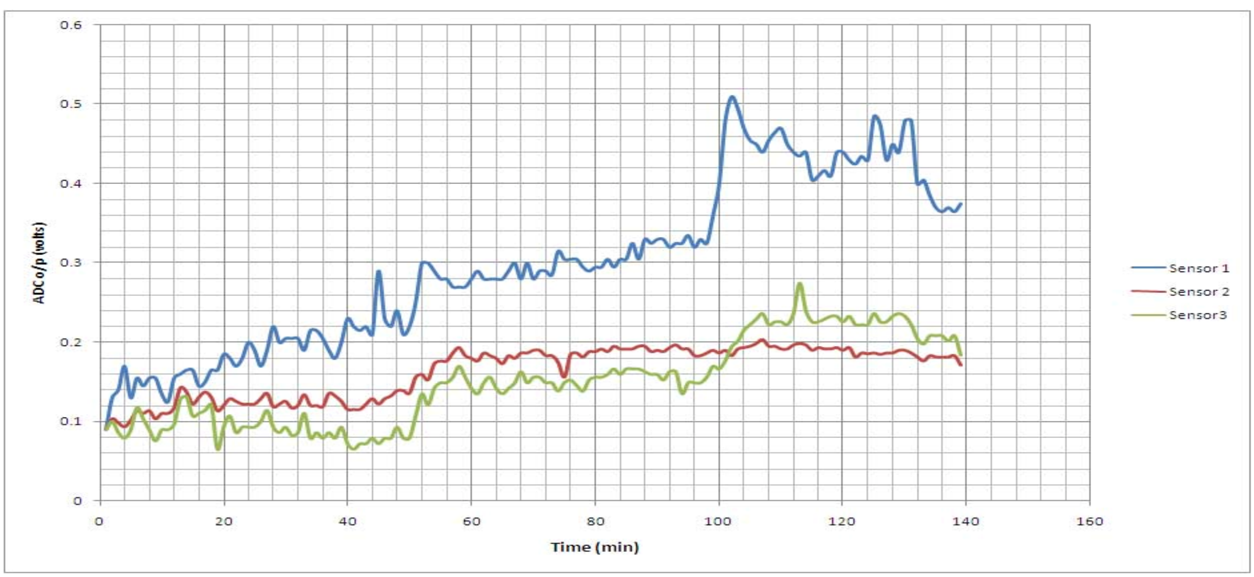

Fig 6: Response of gas sensors

Experiment has been carried out for duration of 1350 minutes. Fig: 7 shows the current consumed by the individual components of the sensor node. We have used hydrogen as sample gas because all three gas sensors TGS 2600, MQ4 and MQ 7 are sensitive to hydrogen. (Fig:6) shows typical gas sensors response corresponding to gas concentration. TGS 2600 shows high sensitivity compared to other sensors because it has detection range from 1 to 100 ppm. The node is powered by dual power source and it has the capability to record and calculate the incoming solar power of the entire day. The typical variation of current produced by solar panel is shown in fig: 8.

(Fig: 9) shows time vs. battery voltage during the course of charging and discharging of battery. It also provides information about the weather variation in entire day. The lab experiments have been carried out by maintaining a fixed temperature of 25 degree centigrade, the sample gas is poured into a environmental chamber. All the devices are battery powered except for the base station, which is powered directly from the grid. A number of trials have been carried out to analyze the performance of the node. During the course of experiment the node sampling rate is fixed to 1 sample per 10 seconds.

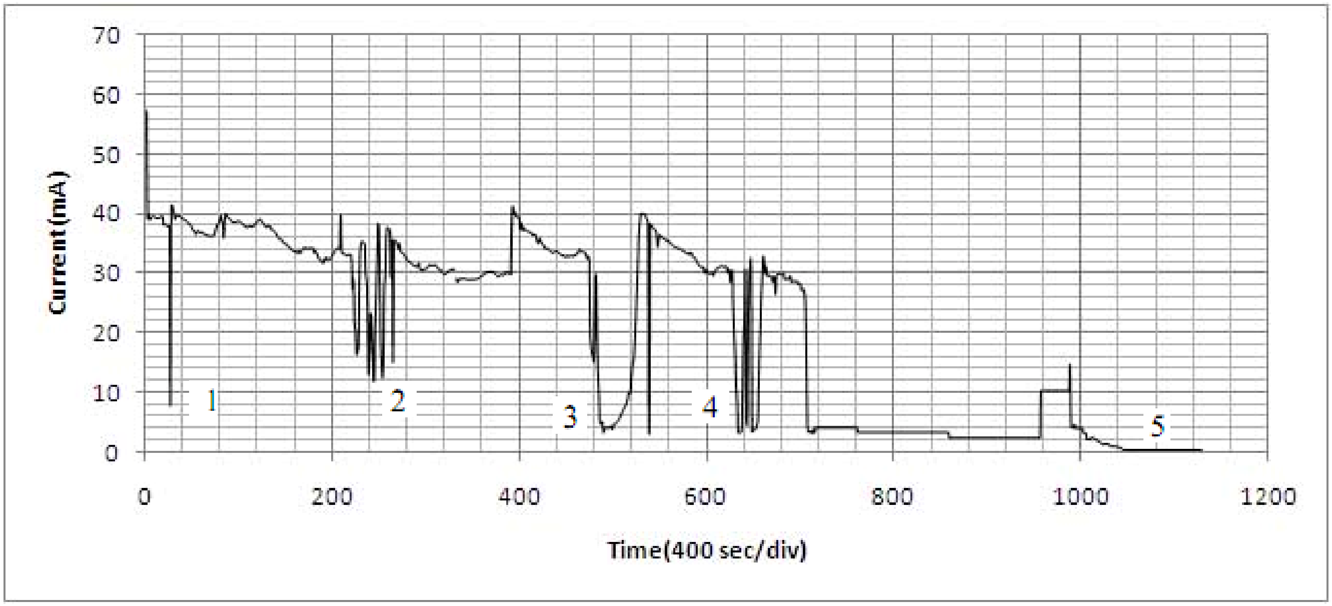

Fig: 8 variation of solar current

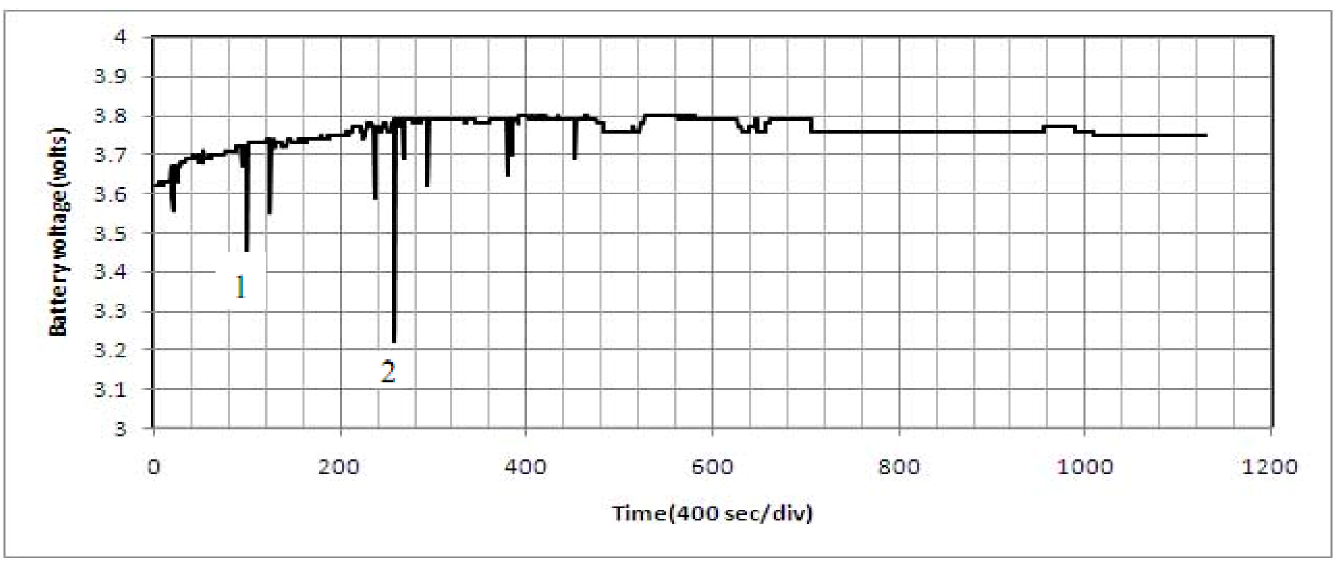

Fig: 9 variation of battery voltage level

VI. SMART TASKING AND PROCESSING

The node hardware is designed to support various smart tasking protocols to enhance life time and flexibility of the node. The worst-case scenario was taken into consideration for average consumption, which is acquisition and transmission of data from the sensors after some time intervals and the calculations shows that the node can still run for 4 days with fully charged battery source without support of the solar power.

$$\bar{I}_{node} = \bar{I}_{stand\text{-}by} + \bar{I}_{sensors} + \bar{I}_{transceiver} \qquad (1)$$

$$\bar{I}_{stand\text{-}by} = 0.25 \text{ mA} \qquad (2)$$

$$\bar{I}_{sensors}=\bar{I}_{MQ\text{-}7}+\bar{I}_{MQ\text{-}4}+\bar{I}_{TGS2600}+\bar{I}_{TSL235R}+\bar{I}_{DS18S20}+\bar{I}_{Humidity\ sensor\ module} \qquad (3)$$

$$= \frac{80mA \times 180}{1800} + \frac{155mA \times 90}{1800} + \frac{65mA \times 90}{1800} + \frac{3mA \times 10 \times 10^{-6}}{15} + \frac{2mA \times 15^{-3}}{15} + \frac{4mA \times 50^{-6}}{15}$$

$$=19.00004151 \text{mA}$$

$$\bar{I}_{transceiver} = \bar{I}_{transmit} + \bar{I}_{receive} \qquad (4)$$

$$= \frac{21.2mA \times 15 \times 10^{-3}}{15} + \frac{13.3 \times 15 \times 10^{-3}}{10}$$

$$=0.04115 \text{mA}$$

$$\bar{I}_{node} = 0.25\text{mA} + 19.00004151\text{mA} + 0.04115\text{mA} \qquad (5)$$

$$=19.29119151\text{mA} \approx 20\text{mA}$$

Expression (2) shows consumption of node at rest. Equation (2) express the average consumption in sensing the data from sensors (MQ-7, MQ-4, TGS2600) for 3min, 1.5min, 1.5min respectively every 30 minute and sensors(TSL235R, DS18S20, Humidity sensor Module) for 10ms, 15ms, 50µs respectively every 15s. Expression (4) shows that the transmitter is switched after every 15s for 15 ms pulse and the receiver is switched after every 10s for 15 ms pulse.

Power management protocol controls the node power consumption depending on incoming power from solar panel to achieve uninterrupted sensing and communication. Therefore various components are switched suitably depending on their start up, data acquisition and transmission timings. The minimum power required to transmit a signal from source to destination depends on some factors like distance, environmental conditions etc. the node has a capability to tune its transmission power which is obtained by analyzing the received signal strength. The node has flexible features by which base station demands the data of any of sensor in priority basis from the node. The deployment of wireless sensor node with solar panel is shown in fig: 10.

VII. RESULTS AND DISCUSSION

We have done several experiments and out of it we got several useful results. In fig:5 we have compared the readings of temperature sensor with a reference thermometer and we observed that both the graphs follow a similar pattern verifying the authenticity of the temperature sensor. Further in fig: 6 sensor1, sensor2 and sensor3 represents the output variation curve of TGS2600, MQ-4 and MQ-7 due to variation in gas concentration respectively. The detection range of Sensor1 is 1-100 ppm for hydrogen gas, This is depicted by the sharp increment in the curve at 96th minute during observation when a small amount of hydrogen gas was poured into the gas chamber. The corresponding increment in output curves of sensor2 and sensor3 are very less.

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Fig: 10: deployment of sensor node

Fig: 8 shows the variation in output current of the solar panel. Spikes 1,2,3,4 represent the variation in the light intensity due to interruption by the clouds. Thus by observing the nature of the curve we can also estimate the variation in light intensity and environmental conditions of the entire day without the use of any supplementary sensors. The marker 5 in the plot depicts the eventual fall in current due to sunset. Fig: 9 shows the varying levels of voltage across the battery terminals as the node is exposed to sunlight. Initially the battery was deep discharged and it started charging on exposure to sunlight which is observed by the increase in potential across the battery terminals as shown in the curve. Spike 1 in the plot shows drop in battery voltage due to triggering of 2 sensors at the same time and spike2 in the plot shows the same for triggering 3 sensors at the same time. By this feature it is possible to record environmental variations of the experimental day.

VIII. CONCLUSION

We have presented work on design and development of wireless sensor node for enviornmental monitoring, the node is enough to provide information about enviornment parameters such as temperature, humidity, light and three different types of gases.during lab based experiments

hydrogen has been used to observe the sensor response.by incrementing various smart tasking protocalls we have succesfully enhanced life time of the sensor node, it is highky dependent on rate of variation of enviornmental parameters We are currently working on improved version of smart sensor node. The aim is to make the sensor nodes more flexible and user friendly with data security and efficiency.

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