Design and Development of a Flexible Reliable Smart Gas Detection System

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ABSTRACT
The advancement of smart sensor technology has allowed us to design and development of a flexible reliable smart gas detection system to detect gases such as combustible air contaminants in the environment. The system composed of three modules the base station, wireless sensor array, and an intelligent wireless alarm unit which offers high reliability, flexibility and uninterrupted sensing, these are achieved by incorporating various intelligent protocols like auto sensor calibration, sensor handover, wireless threshold fixation and intelligent alarm mechanism, the sensor node consists of three gas sensor, one temperature sensor and one pyro-electric infrared sensor (PIR) which enhance the sensing intelligence. Sensed data digitized and processed by peripheral interface controller (PIC) 16f877A based centralized embedded platform and wireless communication is achieved with a pair of 433 and 315 MHz amplitude shift keying (ASK) wireless module. The encoding and decoding of sensed data offer a high secure gas detection system.

Keywords
Smart sensor; uninterrupted sensing; Sensor array; Auto sensor calibration; Sensor handover; Peripheral interface controller.

1. INTRODUCTION
Gas detection systems became a concern after the effects of harmful gases on human health were discovered. Gas detection systems are systems which identify potentially hazardous gas leaks within an area by means of various sensors based electronic systems. These systems also employ an audible alarm to alert people whenever a dangerous gas is detected. These gas detection systems are of immense use because they can be used to detect a wide range of combustible, flammable and toxic gases which have hazardous effects on human health. These are used for a wide range of applications and can be found in industrial plants, refineries, wastewater treatment plants, automobile manufacturing factories etc. Many gas detecting systems have been developed which can detect different levels of gas concentrations effectively [1] [2]. In this paper we report the design and development of a reliable auto configurable smart wireless gas sensing system optimized for industrial application where system smartness and uninterrupted sensing are main concern. This is a typical gas sensing system with some additional features in contrast to other gas detection systems. The system provides highly secured and reliable data transmission over the network, it also detects presence of human at the site of leakage for timely rescue and will alert the appropriate security authority, temperature information sensed by temperature sensor which provides the danger level though gas ignition hardly depends on the environmental temperature and pressure [3], it able to build gas concentration profile of the environment, upon detection abnormality the system will trigger an alarm situated; in such case a text message can be send to any where in the globe using a global system of mobile communication (GSM) modulator and demodulator (MODEM). The system have smart safety features in combustible gas detection and fault tolerance protocol, which provides timed acknowledgment about the health status of the sensor. Two different frequencies are used to perform full duplex two way communication and also eliminates jamming problem. The main advantage of this gas detection system is that the sensor node can be configured remotely from the base station with out altering hardware components. In section 2 is an overview of some work which has been done and is related to this topic. In section 3, we look into the design aspects and challenges associated with the system. Section 4 we have explained the system architecture. In Section 5 describes detail disclosure on hardware description and functionality, section 6 describes various implemented intelligent protocols, various experimental results and there analysis is done in section 7, we conclude the paper in section 8.

2. RELATED WORK
The wireless sensor networks are very popular and are studied widely on the hardware and software configurations and modeling of network performance. Considerable research efforts have been focus towards environmental gas monitoring application. [4] [5] describes intelligent self diagnosis strategy for semiconductor gas sensor. [6] Presents the development of smart sensor network for hazardous gas monitoring by using three types of gas sensors. Some gas detection systems have also been designed and developed. This very year [7] presented implementation of self diagnostic power management protocols smart sensor triggering, sensor handover and auto error detection and correction which enhances the lifetime of the node. A number of research works have been published in last few years in the domain of integrated gas sensors and node. A node with multimode sensors is used for sensing different environmental parameters light, temperature, humidity and different types of gases along with error detection and correction

capability [8]. A sensor node may take various roles depending on the applications of the task requirement and resource availability and limited onboard processing capability. Few studies have been found dealing with practical development of sensor consisting of multiple sensors with various power management protocols. These papers present design of a wireless sensor network which is able to collect the information from sensors, process it and communicate wirelessly in the network for industrial monitoring, agriculture, composting processes etc. [9,10] . As previous studies did not detail consideration related to issues such as system flexibility and reliability, our work here describes in more detail the design and implementation of intelligent protocols in a cost effective gas detection system.

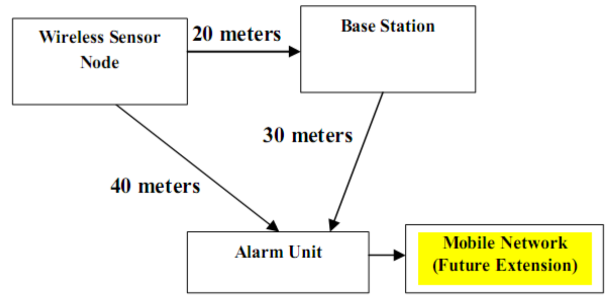
3. DESIGN ASPECTS & CHALLENGES

The system must be able to configure itself, without human intervention due to the fact that this type of system are placed in potentially inaccessible area so self configurable and auto calibration features reduce maintenance cost, the sensors should be positioned near to the source of potential phenomenon, and so all sensors in the network will have a justification for their existence in the system. The semiconductor gas sensors are sensitive to the variation in heater voltage resulting in different adsorption and desorption of gases. Due to their high sensitivity and low cost, semiconductor gas sensors are ideally suited for safety and security applications like fire and leakage detection [11][12]. The major drawback of these types of sensors is poor selectivity, sensor baseline drift, heater voltage dependency, long term instability, and high power consumption which are crustal parameter for a battery powered sensor node. So the system must have the auto calibration features to nullified the offset which require additional reference sensor, reliable communication is another issue specially alarm signal propagation, network problem must not interrupt alarm system, The sensor node should also send the health status in a predefined time interval to ensure node active condition, so in spite of sensed data communication it also must have intelligent protocols which enhances smartness of the system. Due to high power consumption in the heater coil gas sensors must be switched smartly to optimize the node power consumption which directly relates the node life time. Some additional sensors like temperature, humidity, pressure are useful to incorporate in the sensor array which do not participate in gas sensing but provide information about environmental condition. The system may have the provision of network switching to communicate with the GSM network. In this work we have tried to achieve the desired goal and overcome the design challenges.

4. SYSTEM ARCHITECTURE

Fig. 1 shows the deployment strategy of smart gas detection system which consists of three units 1. Wireless sensor node 2. Base station or fusion centre 3. Alarm unit and with cellular modem (future extension), the system has been tested in Sikkim manipal institute of technology, the distance of alarm unit has been chosen in such a way that both senor node and base station can communicate with one hop communication range.

Fig 1: Deployment strategy of smart gas detection system



The sensor node can sense three different parameters gas concentration, environmental temperature, and human existence, these are achieved by three gas sensors in which one is the backup sensor used for auto calibration and sensor handover, one digital temperature sensor and a PIR sensor. Each unit of the system has RF (radio frequency) communication range of 100 meters in free space in which the sensor node and base station has two way communication capabilities. Different operating RF is chosen to avoid jamming. We have also kept provision to interface cellular GSM modem to forward the alarm message to anywhere in GSM network [13].

5. HARDWARE DESCRIPTION AND FUNCTIONALITY

5.1 Wireless Sensor Node

Fig. 2 shows the node prototype for the smart gas detection system, the node hardware can be divided in three different sections such as sensors, centralized embedded system and RF unit. The node have 3 gas sensors two TGS 813 and one TGS 2600, in two TGS 813 one is acts as reference sensor during auto sensor calibration and as substitute sensor during sensor handover. The sensing material in TGS gas sensors is metal oxide, most typically SnO_2. When a metal oxide crystal such as SnO_2 is heated at a certain high temperature at around 400 degree Celsius in air, oxygen is adsorbed on the crystal surface which in turns changes the sensor resistance which is converted to change in output voltage using suitable signal conditioning. The power supplied to the heater coil is responsible for heating the sensor which leads to adsorption of oxygen. Thus, the gas sensors are sensitive to the variation in heater voltage resulting in different adsorption and desorption of gases [14][15]. PIR sensor is used to detect the human existence in the gas detection area and the node reads the PIR sensor data only if the gas concentration level reach the alarm threshold level, they have temperature constraints from -40ºC to 100ºC and work in the range of 4 to 12 µm wavelength, The node have a temperature sensor, 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 microcontroller interface. It has an operating temperature range of –55°C to +125°C. In addition to the sensor signal processing the node perform several additional tasks like dynamic addressing, sensor handover, threshold fixation, intelligent power management which need a central processing unit (CPU) having large number of input output pins, it is achieved by 40pin

PIC 16f877A microcontroller based embedded system platform. It is 8 bit high performance RISC (reduced instruction set computer) processor can execute an instruction in single clock except program branches; it operates at 20 MHz clock and has 8Kx14 words of flash program memory and 256x8 byte of data memory. The data is exchanged between sensor nodes, base station and wireless alarm unit in done by coded 315 and 433 MHz ASK transceiver module. Data encoding and decoding is done by HT 640 and HT 648L 3^{18} encoder and decoder IC, which provides security and unique identity to each sensor node and base station. Fig. 3 and Fig. 4 shows the block diagram and internal components of the node.ULN 2003 is used for actuating the heater of the gas sensor triggered by the microcontroller

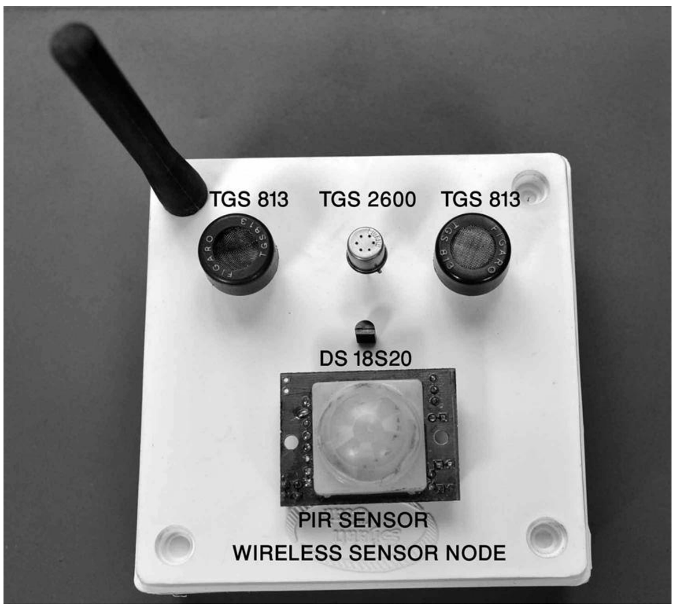


Fig 2: Wireless sensor node prototype

All analog sensor o/p signal is digitized by the internal 10 bit analog to digital converter (ADC) of microcontroller where as digital sensor o/p are directly interfaced with digital i/p pin of the PIC 16f877A.

5.2 Base station and Alarm Unit

The task of the base station to receive the data sensed and processed by the sensor node and sends various command signals to the sensor node and alarm signal to the alarm unit. the architecture of the base station is similar to node except it do not have sensor interfacing part, the alarm and command signal and sensed data can be send or receive through a personal computer (PC) which is interfaced using RS232 serial communication protocol. Base station receive information by 433 MHz ASK receiver but it can send the signal to node or alarm unit by 315 MHz ASK transmitter just altering host ID which will be discussed in later part of the paper. The PIC 18F4550 is used as central processing unit (CPU) for base station. The major components of wireless alarm unit are PIC 16F877A microcontroller; 315 MHz ASK receiver, 3^{18} encoder and decoder, Alarm and display unit and a GSM cellular MODEM.

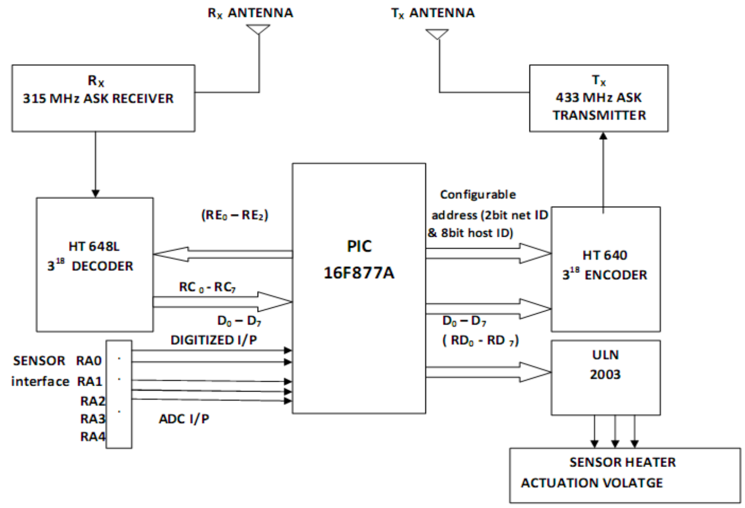


Fig 3: Block diagram of wireless sensor node

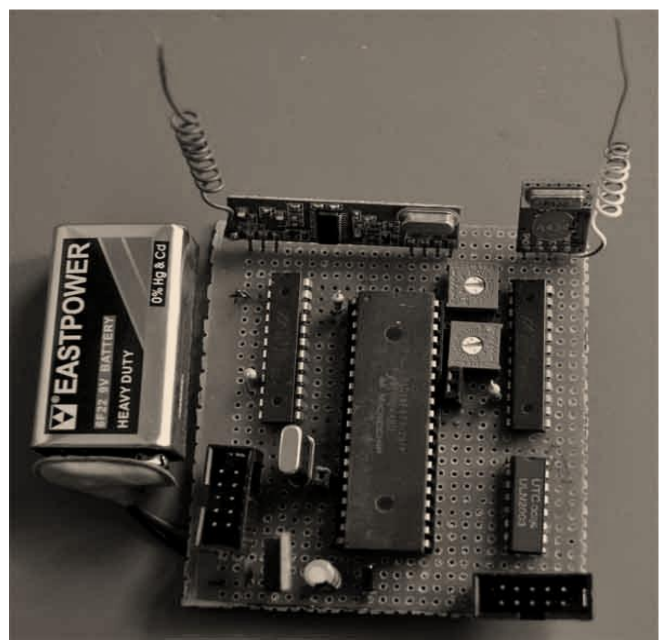


Fig 4: Internal components of the node

The block diagram of wireless alarm unit is shown in fig. 6. In normal condition alarm unit receive health signal at every 5 seconds and incase of any abnormality sensed by the sensor node parallel alarm signal is received from base station and sensor node. A GSM cellular MODEM is connected with the alarm unit to propagate this alarm signal in message form to anywhere in the GSM network.

All the three unit of the system is powered by a 9v battery which is farther regulated to 5v using voltage regulator, use of DC to DC converter will optimum in terms of power efficiency.

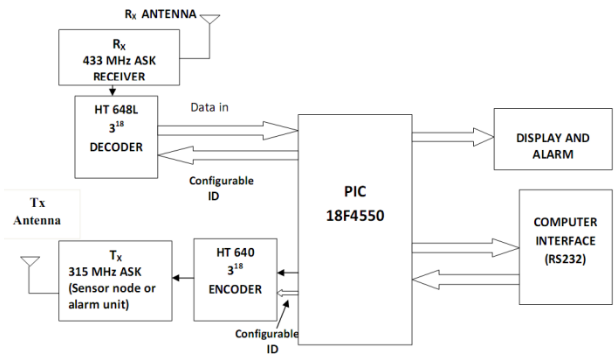


Fig 5: Block diagram of the Base Station

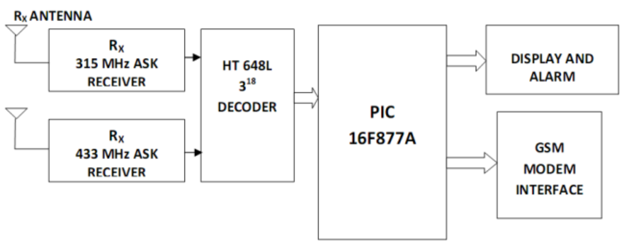


Fig 6: Block diagram of Wireless Alarm unit

6. IMPLEMENTED SMART PROTOCOLS

Various intelligent protocols have been implemented to achieve high reliable and flexible gas detection like intelligent selection, dynamic addressing and reliable data communication, wireless threshold fixation, automatic sensor calibration and error detection and intelligent alarm mechanism.

6.1 Intelligent sensor selection

This protocol describes how node can select appropriate sensor automatically depending on environmental gas concentration. The two sensors TGS 813 and TGS 2600 can be activated by the user or automatically depending on the instructions given by base station. The measurement of gas concentration starts after the settling time has passed in order to prevent false alarm. TGS 2600 and TGS 813have detection range 0 to 100 ppm and 500 to 5000 ppm respectively. If the gas concentration is less then upper threshold level of TGS 2600 then it continues with sensing and TGS 813 is switched off, in other case if gas concentration is greater then upper threshold level of TGS 2600 then TGS 2600 is shut down and TGS 813 starts sensing. This process automatically select appropriate sensor according to environment condition and only one sensor is in activate condition in this way 50% sensor power can be saved though maximum power is consume by the heater coil of a gas sensor.

6.2 Dynamic Addressing and Reliable Data communication

Distinct applications and processes in the industries have disparate safety requirements and functions; this feature incorporates flexibility and security as each node present in the network has a unique network address which changes after certain interval of time, this dynamic ID is fetched from look up table which is stored in the both node and base station. Fig. 8.1 shows 18 bit pattern is divided into 10 bit address and 8 bit data, 10 bit address is farther divided into 2 bit network ID and 8 bit host ID which is configurable and changes time to time in cyclic manner which facilitates a dynamic addressing to the system.

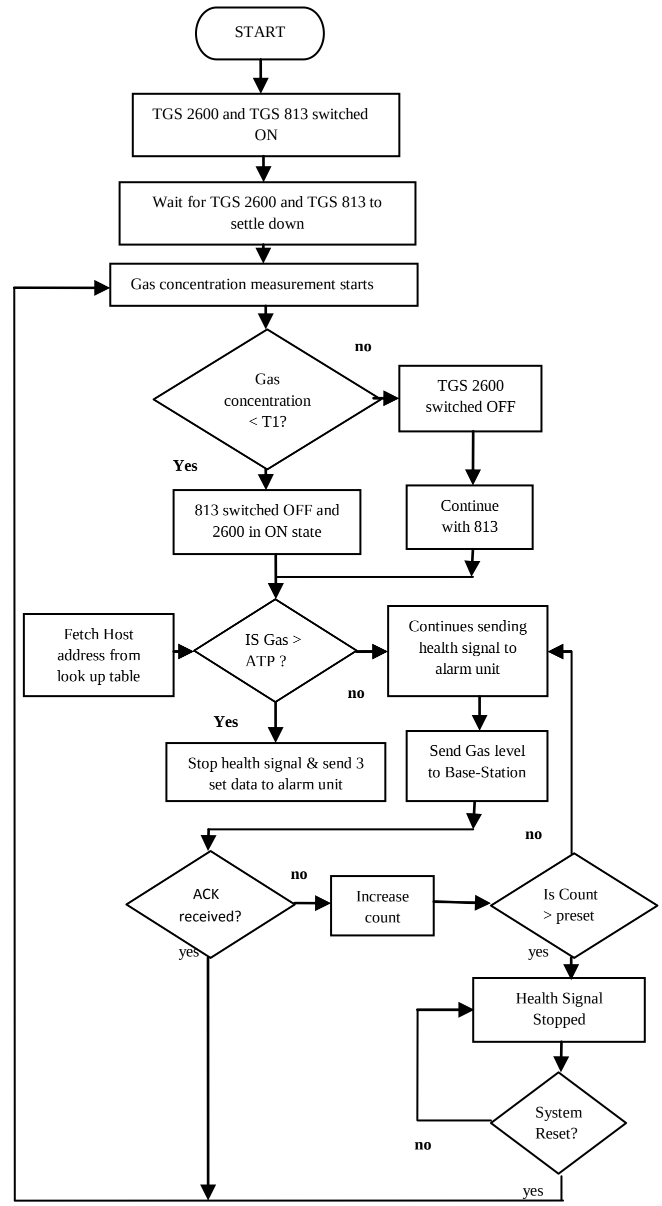


Fig 7: Functionality of wireless sensor node

The node and base station perform unicast communication which consists of receive acknowledgement, sender will send the data repeatedly up to count values if acknowledgement not received and after that it stops sending the health signal to alarm unit, This triggers the alarm and notify about communication failure. When the gas concentration reaches the preset alarm threshold level the warning signal is triggered wirelessly in the alarm unit. Subsequently, sensor node transmits three set data to the base station and alarm unit regarding the condition of the site

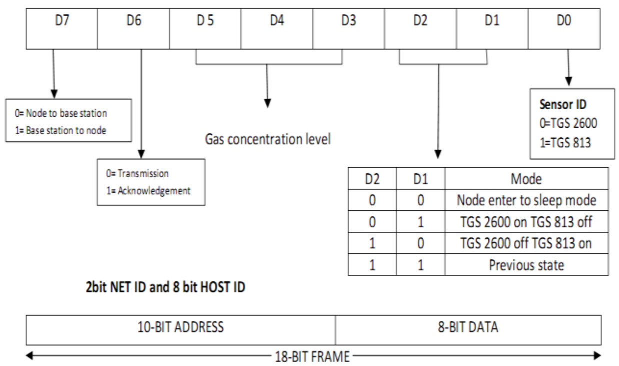


Fig 8.1: Bit pattern for mode selection and addressing

of leakage. This includes the gas concentration level, the temperature level and the presence of human at the site of leakage. An accessional feature which inculcates reliability in addition to flexibility and security is a protocol which continuously monitors the health of the system. This is done with the help of health signal which is transmitted to base station after every three seconds. The base station in return acknowledges the health signal. If the base station is unable to receive health signal for another preset interval, the base station is able to easily identify that there is some problem either in the node or with the communication path. This triggers another alarm in the base station indication a fault and the node then requires a master reset by the concern authority after debugging the error.

6.3 Wireless Threshold Fixation and System Flexibility

The base station can remotely set the threshold level at which node send the alarm signal according to the requirement, Also this threshold level can be set using a wireless remote which is situated away from the base station and the sensor node. The base station and node interacts with each other the node with the 18 bit information, each node has a unique 10-bit address in that two bits are node ID and eight bits are configurable host ID, in eight bit data format and corresponding bit function is shown in fig. 8.1 where D7 specifies the data flow direction, D6 represents signal type whether transmission or acknowledgement, D5-D3 represent the gas concentration level in case of node to base station communication and threshold fixation for alarm when data is send by the base station. The resolution of gas sensing and threshold fixation can be calculated by the following equation,

Sensor upper detection level ($\mathbf{u_{dl}}$)

Sensor lower detection level ($\mathbf{l_{dl}}$)

No of bit assigned for gas concentration (**L**)

$$\textit{Resolution} = R = (u_{dl} - l_{dl}) \div 2^{L}$$

Ann alarm threshold level ($\mathbf{At_l}$) can be calculated by

$$At_l = R * G_{ib}$$

G_{ib} = 3 bit gas information bit caring by (D5 –D3)

The fig. 8.2 describes a table containing eight bit data format and the function associates with it. The first row is a sample data send by the base station to node for fixing threshold level of 3375ppm for TGS 813. After fixing the threshold node send an acknowledgement to the base station with same bits except D7 which is 0 to represents data flow from node to base station and D6 is 1 representing it is an acknowledgement not a sensed data. In case of any wrong acknowledgement send by node base station resend the command for another three times in case of farther wrong information it generates a alarm signal which represents system error, so by these intelligent acknowledgement mechanism the system become more secure and reliable. The sensors situated in the node can be on/off from the base station which provide a high flexibility and also it is very important respect to power management so respective sensor can be shut down independently when they do not participate in sensing. The third sample data shows eight bit pattern for triggering TGS 813 and shut down of TGS 2600. In same way after completion of the task node send an acknowledgement, which is shown in forth sample data fig. 8.2. The system have self error detection features that is irrespective of alarm signal the node send a coded commend to the remote station wirelessly after every 5 seconds which carries the health information of node and wireless communication system, failure in reception of this health commend signal also triggers the alarm which shows the auto error detection of the system, the health signal is shown in last sample data in fig. 8.2

D7	D6	D5	D4	D3	D2	D1	D0	Function
1	0	1	1	0	1	1	1	Base station to node, transmission, fixing threshold level for 813 at $((5000-500/2^{3})*6)$ = 3375 ppm
0	1	1	1	0	1	1	1	Acknowledgement of fixing alarm threshold point at 3750 for TGS 813.
1	0	*	*	*	1	0	*	Trigger TGS 813 and shut down TGS 2600
0	1	*	*	*	1	0	*	Acknowledgement by the node regarding sensor switching
0	1	1	1	1	1	1	1	Health signal

Fig 8.2: Sample data for threshold fixation, sensor triggering and health signal.

6.4 Automatic Sensor Calibration and Error detection

Depending upon uses the sensitivity curve of the sensor changes time to time which interns in incorrect reading, so to avoid this the sensor must calibrate in regular interval to get error free data which need high maintenance cost. We developed an algorithm which calibrates a sensor automatically in every 12 hours by the help of another standby sensor situated in the node. Fig. 9 shows the functional diagram of automatic sensor calibration and error detection. Calibration process starts by actuating both the sensors (backup and base sensor) now both the sensor sense the environment and compare their outputs which results mainly three types of result, first if the deviation between the sensors are zero or less then threshold point then no action is taken, and backup sensor is kept for standby position until next calibration Cycle starts. In second case, if the deviation is larger than threshold an offset is added or subtracted from the senor output. And in third case if the offset is larger than correction limit then the base sensor will turn off and backup sensor will act as base sensor, this is called sensor handover, and the same information will be forwarded to the base station, in this way in case of mull

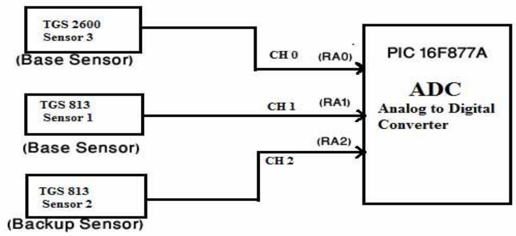


Fig 9: Functional diagram for sensor calibration and Sensor handover

functioning of any sensor an uninterrupted sensing is achieved by implementing sensor handover protocol.

6.5 Intelligent Alarm Mechanism

The alarm unit perform one way communication from node or base station to the wireless alarm unit, so the system should be enough intelligent for high reliability Fig. 10 shows the flow chart how does an alarm signal generate and propagate to alarm unit.

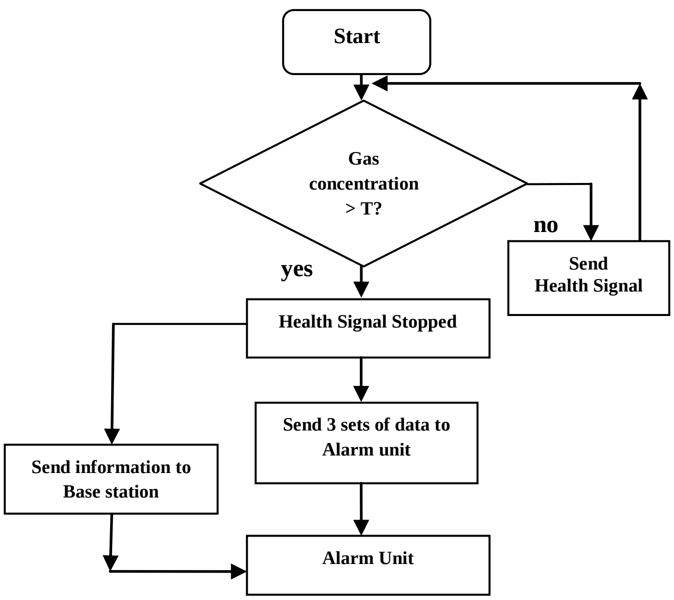


Fig 10: Alarm signal generation and propagation

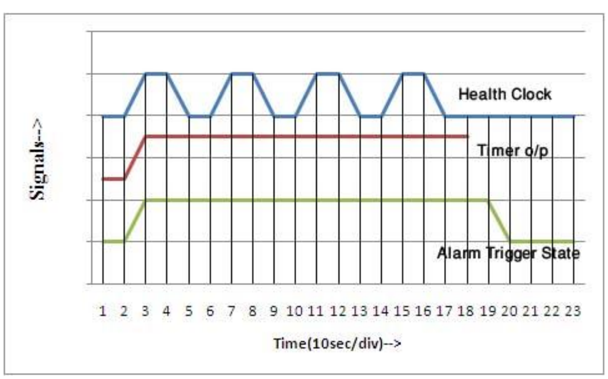


Fig 11: Timing diagram for alarm signal generation

Normally an alarm signal generates in a system whenever some abnormality occurs in the system, but it is not a reliable protocol because in case of communication failure or system error instead of an abnormality the alarm signal cannot propagate to wireless alarm unit. So we have followed the reverse process fig. 11 and fig. 12 shows the flow chart for alarm signal generation and propagation and timing diagram of alarm signal generation. In case of normality the node keep on sending the health signal in every five seconds. Which trigger the Retriggerable monostable multivibrator whose time period is set to 7.5 seconds, so if health signal is received continuously by the alarm unit the output of multivibrator become high so alarm does not trigger, but if any abnormality reported node do not send any health signal which results in triggering the alarm after 7.5 second of last health signal received, the time laps can be reduced by increasing the sampling rate of the health signal. The time ratio between health signal and multivibrator must be 1:1.25.

7. EXPERIMENTS & RESULTS

A number of extensive experiment have been carried out to study the various behavior of gas sensor and to test the wireless gas detection system. During lab based trial we kept the sensor node in a glass chamber and then we inserted isobutene as trial gas. The experiment is divided into four different phases the combined response of the gas sensor TGS2600 in these four phases can be found in fig. 12 which is obtained in base station and then send to personal computer for storage and statistical analyses. In first phase in the absence of gas we have seen the initial response of TGS 2600 which is approximately 2 minutes. From the curve fig. 13 it is clear that the sensor will be ready to use after this initial response time only using the sensor in phase one would give wrong result. In phase two we inserted the gas and observed that sensor reacts very fast when the gas concentration is increasing inside the chamber.

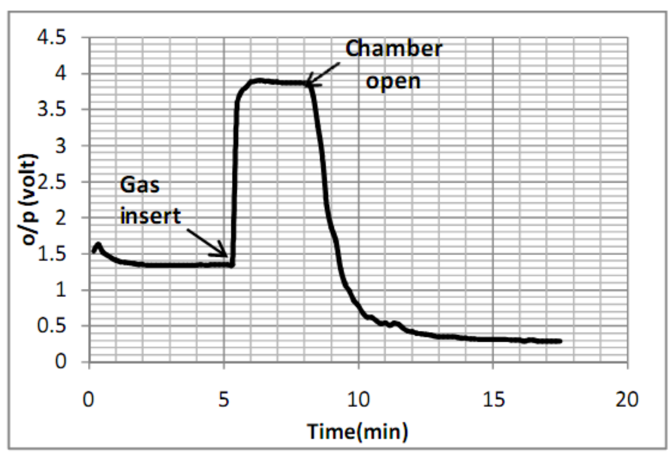


Fig 12: Total response curve of TGS 2600

The phase three is carried out for approximately 4 minutes which was the holding period during this phase we did not alter the gas concentration level. In the forth phase we certainly open the chamber and observe the settling characteristics of the gas sensor. We found one Interesting characteristics during forth phase spike ‘A’ in fig. 13 found which shows the increments of gas concentration level, but practically gas concentration was

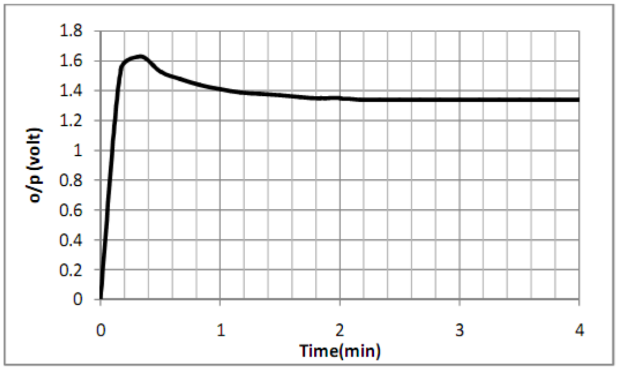


Fig 13: Initial response of TGS 2600

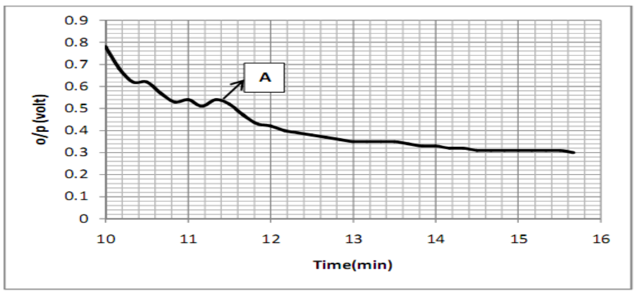


Fig. 14 Behavior of TGS 2600 in forth phase

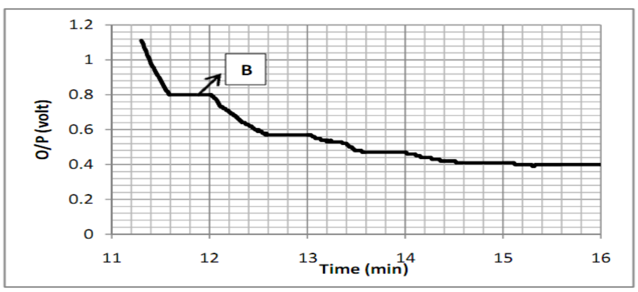


Fig. 15 Repeated behavior of TGS 2600 in forth phase

decreasing. To verify the cause we repeat the experiment and found a step response during that period spike 'B' in fig. 14, so authors have taken this task for future work. Varies command also send to the node and we have got appropriate acknowledgement signal from the node.

8. CONCLUSION

We have presented a work on the design and development of a wireless smart sensor node for the use in industries to provide information about any gas leakage and its notification through wireless transmission at a warning unit situated far away from the base-station. We have also shown that the threshold level at which the warning unit turns on and notifies of the gas leakage can be set manually in two ways. First is that it can be set manually by the base-station through the 8-bit data and second is by the remote control placed far away from the base-station. The base-station is notified of the threshold level change and the monitoring continues. Finally the warning unit triggers the warning signal when the ppm level reaches the threshold level and this information is sent to the base-station. Further we have shown the Smart, Safe and Reliable transmission of data by providing address change after certain interval which will thereby give reliable and efficient data. This work therefore successfully secured the wireless data transmission and reliable notification about the gas leakage.

9. ACKNOWLEDGMENT

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