Design and Implementation of a Wearable Gas Sensor Network for Oil and Gas Industry Workers

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Abstract: Industrial environment usually involves some types of hazardous substances including toxic and/or flammable gases. Accidental gas leakage can cause potential dangers to a plant, its employees and surrounding neighborhoods. Around 64% of accidents that happen in the oil fields are due to combustibles and/or toxic gases. The safety plan of most industries includes measures to reduce risk to humans and plants by incorporating early-warning devices, such as gas detectors. Most existing tools for monitoring gases are stationary and incapable of accurately measuring individual exposures that depend on personal lifestyles and environment. This paper provides a design and implementation of a wearable gas sensor network by building sensor nodes with wireless communication modules which communicate their data along the network. The system is designed to be flexible, low cost, low maintenance and with accurate performance to detect toxic gases in a timely fashion to warn employees before an existence of a disaster.

Key words: Wireless sensor network, gas detection, toxic gases, wearable gas sensor.

1. Introduction

Currently wireless sensor networks (WSNs) are being used in different applications. They have various features, such as low cost, low power consumption, reduced maintenance time, improved tools performance and enhanced safety which make it a feasible solution for many industries. For instance, the oil and gas industry includes processes for exploration, extraction, refining, transporting, and marketing petroleum products [1] and this can also be found in the steel, aluminum, mineral, automotive, medical, agricultural, aroma and food industries. Wireless gas sensors usually have limited resources, such as processing unit, power supply unit, and storage. However, when they work together to do a specific task, they accomplish an accurate description of the physical phenomena that we need to measure. Moreover, The property of wireless technology allows the sensor network to be deployed in a harsh environment or in a place where the wired network is difficult or impossible to be deployed or in unreachable area [2]. For the current growth in ubiquitous computing and communication, wearable sensors technologies are getting more attention and more research [3], [4] has been done in such fields like healthcare [5], safety [6], and environment [7]. As a result, wearable sensors can assist to save human lives [8] and monitor environmental issues. Forsyth *et al* [9] proposed a wearable system, which can be attached to helmet, to protect a construction worker from carbon monoxide poisoning. The sensor design consists of an Xpod oximeter, an Xbee communication module, and a battery as a power supply. Nikzad *et al* [10] presented a wearable device (CitiSense) that functions as an air quality sensing system. It communicates with smart phone via Bluetooth to display the most recent air quality measurements and communicates with a web server to allow users to reflect on their overall exposure to pollutants. Manes *et al* [11] developed a wireless sensor network for volatile organic compounds (VOCs) detection. The network has many coordinator nodes equipped with climate sensors like temperature, humidity, wind direction and speed, solar radiation, and a rain gauge. Also the network has end devices equipped with VOCs detection sensors distributed in well-identified locations within the plant. Mead *et al* [12] developed a system with static and wearable end devices to measure carbon monoxide (CO), nitric oxide (NO), and nitrogen dioxide (NO2) in air. The sensor node is autonomous and incorporating with gas sensors, GPRS for communication and GPS module. The wearable sensors were designed to be lightweight and convenient to wear whereas the static sensors are more powerful with larger gas sensors, long battery life, temperature, and humidity sensors being added. The disadvantage of the previous system is that each node works autonomously and for this reason Khaled Hossain *et al* [13] enhanced the system by developing nodes which can communicate with each other for long-term measurements of the global warming increase .

Our mobile system complements a static systems [14], [15] to accurately measure toxic and combustible gas around individuals and send warning messages to other workers and contains one sensor (MQ-7) that can sense Carbone monoxide (CO) and Methane (CH4) instead of CO only. In addition, an innovative method to reduce the power consumption of the sensor node by using accelerometer and on-demand switching on/off the GPS, communication module and sensor. Next section presented the development of the system in details. Section 3 reports the experiment conducted to the system. Finally, conclusion is stated in section 4.

2. Proposed System

Fig. 1 shows the architecture of system which consists of three levels of nodes: Sensor nodes which is a wearable sensor that senses the existence of toxic gases and provides the wearer with a proper alarm, Routers which can relay the sensing data to a coordinator, and a coordinator node that coordinates the network and directly connect to the computer.

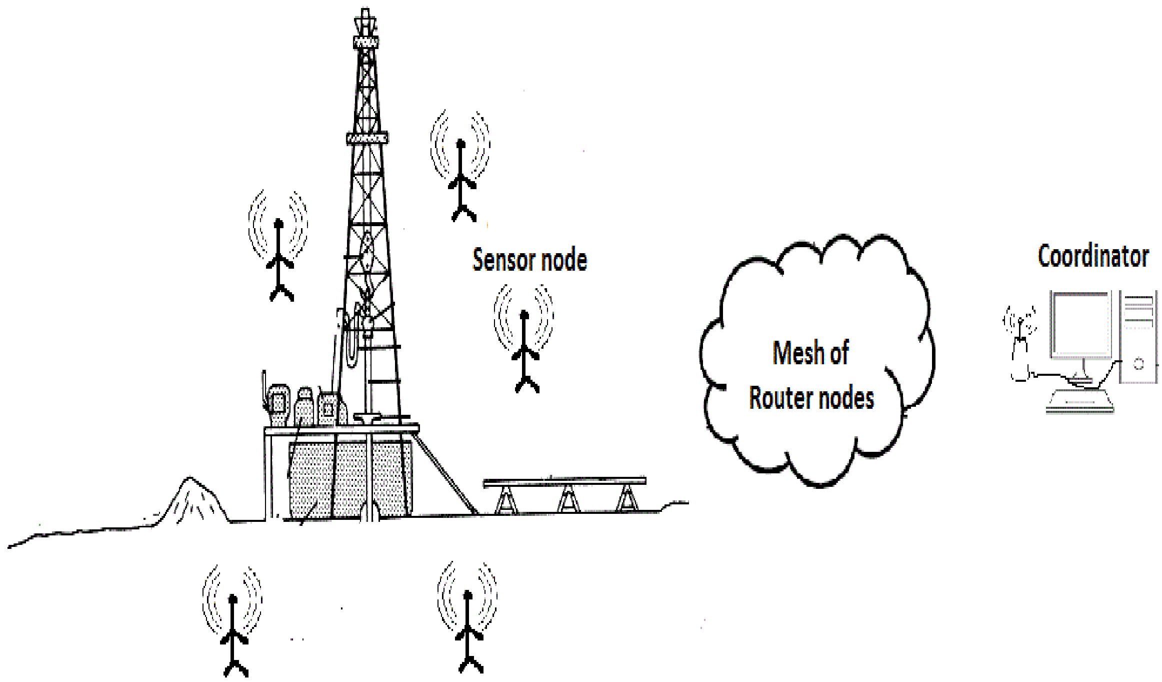

Fig. 1. System architecture.

2.1. Sensor Node

The wearable node is basically a stack of several boards starting with Arduino board [16] as a base, GPS module on top of it, then XBee [17] module on top of XBee shield, and sensor board shield on top level, which makes the system look compact in size and very handy to use as depicted in Fig. 2.

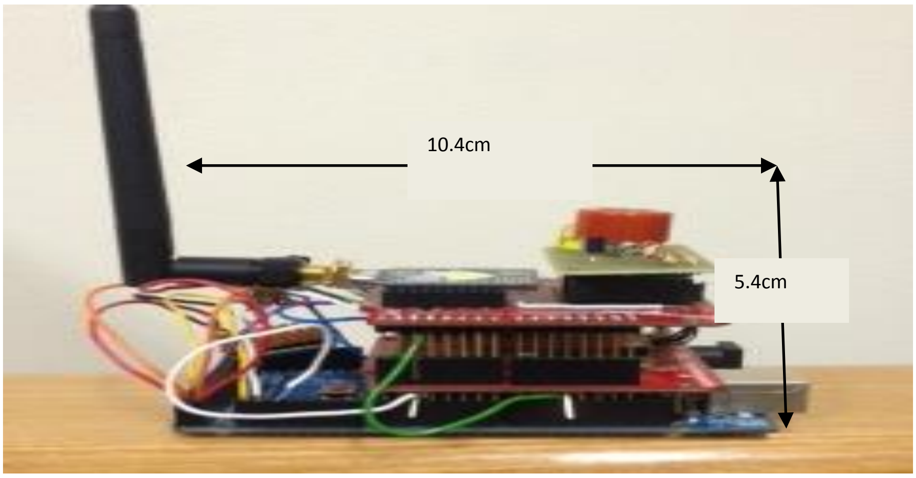

Fig. 2. Sensor node.

2.1.1. Gas sensor

A semi-conductor gas sensor acts as a variable resistor whose resistance either falls or rises (depending on the semi-conduction's doping) during gas leakage. As such the sensor is connected in a potential divider with 10k resistor and the voltage is measured with reference to the ground. A mathematical model is derived in order to determine the concentration of gas in a given area. The graph from datasheet [18] is used to obtain (R_s/R_o) where R_o is sensor resistance at 100ppm of CO in the clean air and R_s is sensor resistance at different concentrations of gases. It should be noted that R_s is described in terms of voltage drop across the resistor instead of Ohms. This is possible because the earlier and the latter are directly proportional. The model is represented by the following equations:

$$CO_c = 106.73 * \left(\frac{R_s}{R_o}\right)^{-1.508} \tag{1}$$

$$CH4_c = 2 * 10^{13} \left(\frac{R_s}{R_o}\right)^{-10.13} \tag{2}$$

The ideal way to calibrate the gas sensor (MQ-7) is to obtain measurements in known concentrations of CO. However, due to toxicity of the gas it is quite difficult to setup this environment. The other way is to obtain gas measurements in absence of CO; the equation below illustrates that using voltage divider:

$$I_{R_L} = I_{R_S} \tag{3}$$

$$\frac{V_{R_L}}{R_L} = \frac{V_{R_S}}{R_S} \tag{4}$$

$$\frac{V_{R_L}}{R_L} = \frac{(V_{in} - V_{R_L})}{R_S} \tag{5}$$

$$R_S = \frac{(V_{in} - V_{R_L}) * R_L}{V_{R_L}} \tag{6}$$

where the VRL is the voltage drop on the load resistance, Vin is the input voltage. Now R_o indicates the resistance of MQ-7 at low concentration of CO so that the value of R_s/R_o should be near the value when there is no existence of toxic gases.

2.1.2. Gas sensor software

The software developed for gas sensor nodes are installed in the Arduino microcontroller board. Fig. 3 depicts a flowchart designed for the program of the sensor node. At the beginning, the sensor listens for 30 seconds to detect if the coordinator sends another sensor's reading. If the sensor receives data, it checks whether this data is within the concerned area, in order to start an alarm and to check a sensor movement. On the other hand, if no data is received, the sensor node detects the movement. If no movement, it goes to sleep for 30 seconds (this is a tunable parameter according to the nature of the application); otherwise it turns on the gas sensor and the GPS is also powered. The node then allows the gas sensor to heat up and the GPS module to synchronize with GPS satellites while it carries out other activities. After getting sensing readings from MQ-7 sensor, it sets the alarm on if the readings are above a threshold and broadcasts the data. Then it detects the sensor movement to send data more frequent. If the reading is below the threshold, it broadcasts directly through the Xbee module and goes to sleep for one minute to save power (this is a tunable parameter according to the nature of the application).

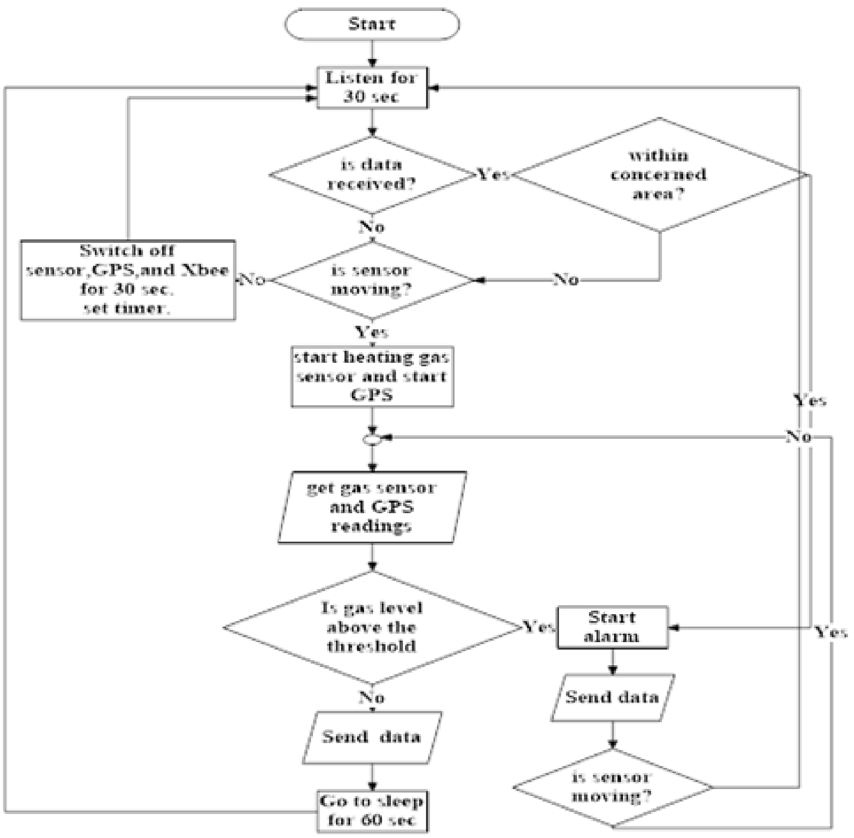

Fig. 3. Sensor node flowchart.

2.2. Coordinator Node

The coordinator node acts as a sink to the sensor network and gateway between the network and coordinator's PC. It collects data form the network and sends it to the coordinator's PC via serial connection. The Coordinator's PC is programmed to receive data from the sensor network and process it as shown in Fig. 4. The program listens to the COM port selected where the data will come from. As soon as serial data is received, checksum is calculated and compared with the received checksum (i.e. the value in the last field of the frame) and the system returns to its listening state when the data is received with errors. After receiving correct data, the coordinator node starts an alarm and sends notification to the other end nodes if the gas is above the threshold. Then it adds a node record in case that the node is sending to the coordinator node for a first time. If it is already added, it updates the node record and checks the existence of nodes which mean that all workers are in their positions. It reports the missing node if it is not receiving its data for a long time.

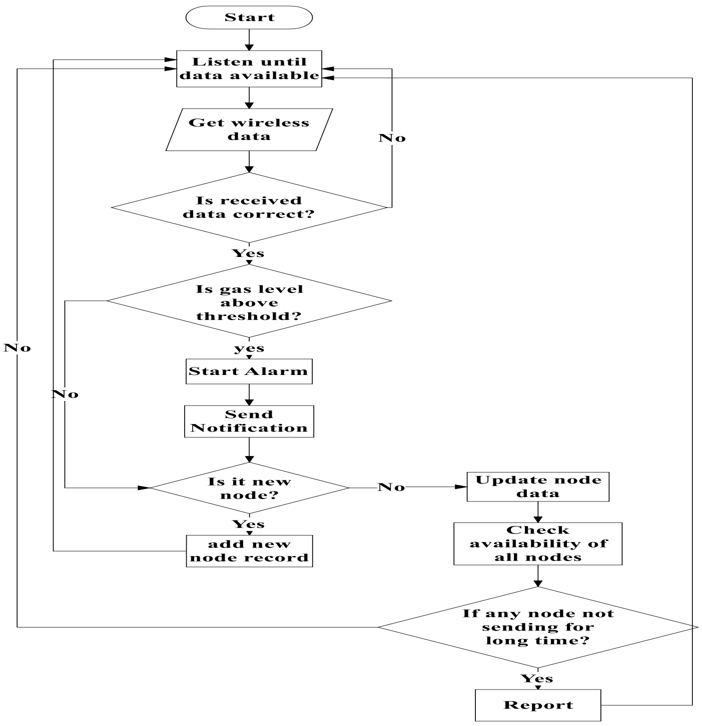

Fig. 4. Coordinator node flowchart.

2.3. Router Node

To increase the distance of communication between the sensor node and the coordinator, a router node can be deployed in a field to ensure that the concern area is covered. Router nodes consists of Arduino module with Xbee module and do not require any special programming. It is responsible for moving data for one node to another.

3. Experiments

Any system is expected to work according to the expectation. The proposed system needs to pass this hurdle by giving good results during its initial testing period. The first system test experiment is conducted at night outside collage of computer science and engineering at King Fahd University of Petroleum and Minerals (KFUPM). The sensor node is placed in different locations, which are at distance of 70-80 meters form the coordinator. The coordinator program collected the sensor node data and displayed it on a serial monitor in coordinator PC. Fig. 5 and 6 outline CO and CH4 concentration in air with time.

The second experiment is conducted in a free space in student housing area in the morning. This experiment tests a multi-hop connection where a router node is placed between the coordinator and the sensor node. The router node is approximately 55m far from the coordinator and between 50-70m from the sensor node, due to the movements of sensor node. Fig. 7 shows the concentration of CH4 which remains stable at around 2000 ppm on average at first. Then, when CH4 is applied to the sensor, it shows significant rise in the concentration of CH4, which means detection of toxic gas and the sensor starts alarm and turns on CH4 LED. In addition, Fig. 8 illustrates the concentration of CO overtime during this experiment. It shows slightly increase with reference to the time when the CH4 was applied to the sensor because the change in the sensor voltage, however it still below the threshold (i.e. 25 ppm and 30000 ppm for CH4 and CO respectively).

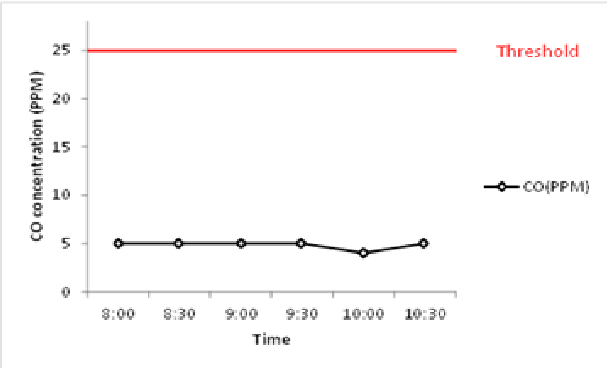

Fig. 5. CO concentration.

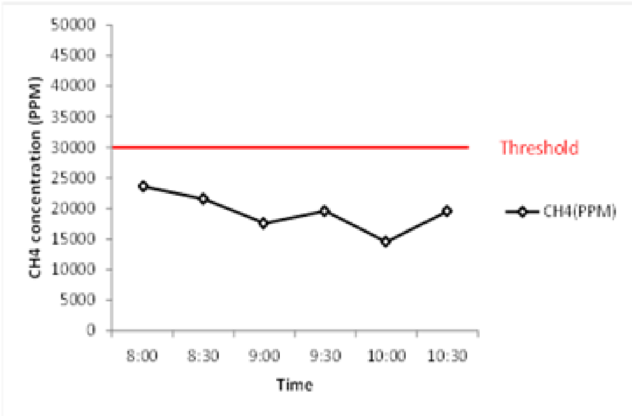

Fig. 6. CH4 concentration.

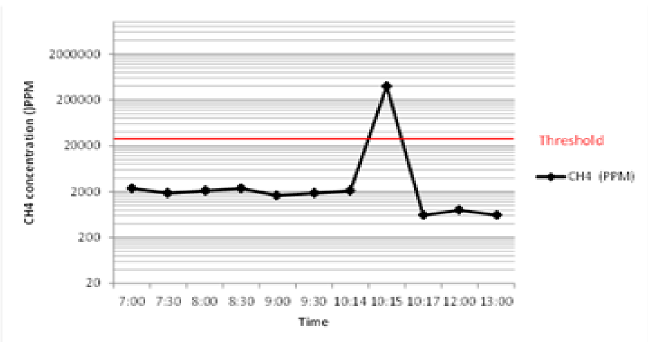

Fig. 7. CH4 concentration.

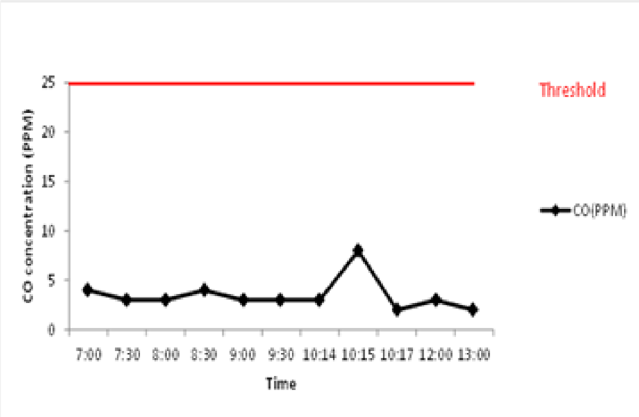

Fig. 8. CO concentration in the second experiment.

4. Conclusion

In this research, we have developed a wearable gas sensor network that overcomes the challenges of implementing an inexpensive, low maintenance, and rapidly responding network to measure several toxic gases (i.e. CO and CH4) by using one gas sensor. The experimental results outline the ability of the sensor to accurately detect the change in concentrations of CO and CH4. However, the sensor reading was affected by climate conditions (i.e. temperature and humidity) during the day time. The power consumption of the sensor node is reduced by using sleeping period and on-demand switching ON/OFF the sensor components with the help of accelerometer. By using rechargeable solar battery the life time of the sensor can be increased to several years because the sensor node consumes only 1.6W. The system can be improved by adding more gas sensors such as H_2S, NO, and HCl. Moreover, Web portal creation can be developed in this system in order to make all data available in public domain.

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