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| التاريخ الميلادي: | 2016 |
| موقع: | الظهران |
| الصفحات: | 1 - 73 |
| رقم MD: | 775191 |
| نوع المحتوى: | رسائل جامعية |
| اللغة: | English |
| الدرجة العلمية: | رسالة ماجستير |
| الجامعة: | جامعة الملك فهد للبترول والمعادن |
| الكلية: | عمادة الدراسات العليا |
| الدولة: | السعودية |
| قواعد المعلومات: | Dissertations |
| مواضيع: | هندسة الحاسب الآلى، شبكة حساسات الغازات، الغازات السامة، الصناعات البترولية |
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IMPLEMENTATION OF A WEARABLE GAS SENSOR NETWORK

FOR OIL AND GAS INDUSTRY WORKERS

BY

ADEL MOHAMMED SOLAIMAN BINAJJAJ

A Thesis Presented to the

DEANSHIP OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the

Requirements for the Degree of

**MASTER OF SCIENCE**

In

COMPUTER ENGINEERING

April 2016

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN- 31261, SAUDI ARABIA

**DEANSHIP OF GRADUATE STUDIES**

This thesis, written by **ADEL MOHAMMED SOLAIMAN BINAJJAJ** under the direction his thesis advisor and approved by his thesis committee, has been presented and accepted by the Dean of Graduate Studies, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN COMPUTER ENGINEERING.**

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23/5/16

**Date**

*To my late father, my mother,*

*my brothers and my sisters*

# ACKNOWLEDGMENTS

In the name of Allah, Most Gracious. All praise is to Almighty Allah who gave me courage, knowledge and ability to complete this work and blessing of Allah be upon his prophet Mohammed (peace be upon him).

I wish to express my deep appreciation and thanks to Dr. Tarek Rahil Sheltami, thesis advisor, and Dr. Yahya Ismail Osais, and Dr.Muhammad Y. Mahmoud, committee members, for the their guidance and professional advise without which the success of this project cannot be possible. I would also like to show my appreciation to Mr. Farouq Muhammed Aliyu and Mr. Yau Garba whose advice led to the project itself.

Acknowledgment is due to King Fahd University of Petroleum & Minerals. My sincere appreciation is extended to all faculty and staff of the Computer Engineering Department for the contribution to this work. Finally, I would like to thank Kingdom of Saudi Arabia, Hadhramaut Establishment for Human Development (HEHD), family, friends and all well-wishers for their support and encouragement, which serve as a driving force for this research and my study at large.

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| | | |
|---|---|---|
| **WSN** | : | Wireless Sensor Network |
| **LED** | : | Light Emitting Diode |
| **MOS** | : | Metal Oxide Semiconductor |
| **GPS** | : | Global Positioning System |
| **ADC** | : | Analog to Digital Converter |
| **PCB** | : | Printed Circuit Board |
| **CO** | : | Carbone monoxide |
| **CH4** | : | Methane |
| **VOC** | : | Volatile Organic Compounds |
| **PPM** | : | Part Per Million |
| **UART** | : | Universal Asynchronous Receiver/Transmitter |
| **AODV** | : | Ad hoc On-demand Distance Victor |

# ABSTRACT


Full Name : Adel Mohammed Solaiman Binajjaj

Thesis Title : Implementation Of A Wearable Gas Sensor Network For Oil And Gas Industry Workers.

Major Field : Computer Engineering

Date of Degree : May, 2016

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 [1].The safety plan of most industries includes measures to reduce risk to humans and plants by incorporating early-warning devices, such as gas detectors [2]. Most existing tools for monitoring gases are stationary and incapable of accurately measuring individual exposures that depend on personal lifestyles and environment. This proposal 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.

# ملخص الرسالة

الاسم الكامل :عادل محمد سليمان بن عجاج.

عنوان الرسالة : تنفيذ شبكة حساسات الغازات والقابلة للارتداء للعاملين في صناعة النفط والغاز .

التخصص :هندسة حاسب آلي.

تاريخ الدرجة العلمية: :أبريل 2016م.

تحتوي البيئة الصناعية على انواع من المواد الخطيرة والتي تتضمن الغازات السامة والغازات القابلة للاشتعال.تسرب الغاز في مثل هذه البيئة يسبب خطر محتمل للعاملين او المصنع نفسة او البيئة المحيطة. تقدر نسبة الحوادث الناتجة عن الغازات السامة والقابلة للاشتعال في صناعات البترول بحوالي 64%. خطط السلامة في معظم الصناعات تتلخص في تقليل الخطر على الاشخاص والمصانع بواسطة اجهزة تحذير استباقية مثل مستكشفات الغازات. ولكن معظم هذه الاجهزة تكون ثابتة ولاتعطي قياسات دقيقة لبيئة المحيطة بالشخص والقريبة منه. لذلك قمنا في هذه الرسالة وهذا البحث بتقديم تصميم وعمل جهاز قابل للارتداء يقوم بكشف الغازات السامة والقابلة للاشتعال وعمل شبكة في مابين هذه الاجهزة باستخدام جهاز متحكم ووحدة اتصال لاسلكي و مستشعر. النظام هذا سيكون له عدة خصائص مثل المرونة وقلة الكلفة وقلة الصيانة وقابلية التوسيع والاداء لاكتشاف الغازات السامة في وقت معقول قبل حدوث اي كارثة.

# CHAPTER 1

# INTRODUCTION

Currently wireless sensor networks (WSNs) are being used in different applications shown in Table 1. 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 [3] 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, 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.

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 [4].

Enhancing the use of this technology can be done through three methods: mathematical methods, simulations method and/or real-time experiments. In this research a real-time experiment is conducted in order to come up with a prototype to be used for monitoring toxic gases in oil and gas industries.

**Table 1 Different applications used wireless sensor network**

| Applications | |
|---|---|
| Automobiles | ▪ Car ventilation control<br>▪ Filter control<br>▪ Gasoline vapor detection<br>▪ Alcohol breath tests |
| Safety | ▪ Fire detection<br>▪ Leak detection<br>▪ Toxic/flammable/explosive gas detectors<br>▪ Boiler control<br>▪ Personal gas monitor |
| Indoor air quality | ▪ Air purifiers<br>▪ Ventilation control<br>▪ Cooking control |
| Environmental control | ▪ Weather stations<br>▪ Pollution monitoring |
| Food | ▪ Food quality control<br>▪ Process control<br>▪ Packaging quality control (off-odors) |
| Industrial production | ▪ Fermentation control<br>▪ Process control |
| Medicine | ▪ Breath analysis<br>▪ Disease detection |

## 1.1 Motivation

### 1.1.1 The effects of air pollution on human health

Airborne pollutants are known to threaten human health and safety, causing discomfort, illness, and even death, particularly among susceptible individuals, such as those with pre-existing cardiovascular or respiratory problems as well as infants and the elderly [5][6]. Exposure to air pollutants including toxic gases consistently ranks among the leading causes of illness and mortality. Such proof is found in the number of poisonings which occur due to the inhalation of certain gases and aerosols in the air we breathe [7]. In all of these instances the air acts as a medium that allows, and may even assist, the conveyance of the noxious agent from its source to the human host. There is less agreement among health authorities on the significance of the relationship of gases and aerosols in terms of disease, except when these substances appear in the air of work-places, or when cases of patent gas poisoning occur.

The air we breathe has not only life-supporting properties, but also potential life-damaging properties. Under ideal conditions, the air that we must inhale has a qualitative and quantitative balance that maintains the well-being of man [7]. When the balance among the air components is disturbed, an individual's health may be adversely affected, the kind of injury sustained and its degree being dependent upon the nature of the disturbance.

### 1.1.2 Monitoring air pollutants

There is a lack of research conducted in monitoring toxic gases in oil and gas industries using wireless sensor networks. The already existing research focuses on either static sensors [8] or portable devices [9]. It is suggested that a wearable gas sensor network would be a suitable technology to be employed in such industries; however the design of a wearable gas sensor should be easy to use, comfortable, and small.

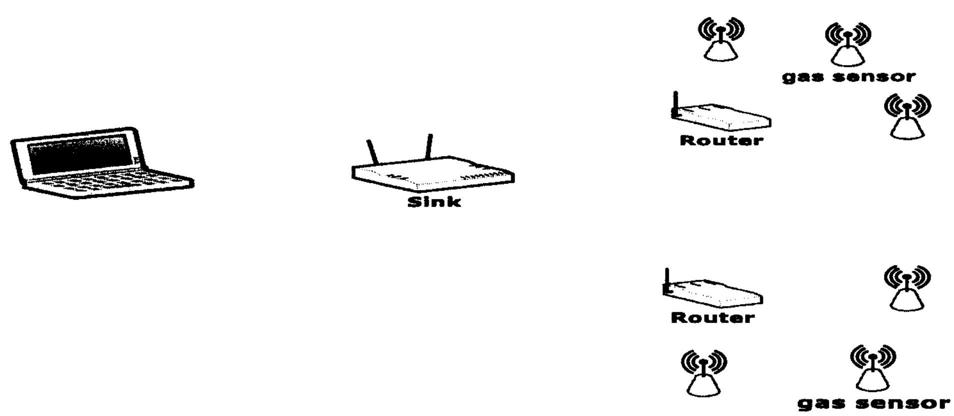


**Figure 1 Toxic gas detection network**

### 1.1.3 Oil and gas fields safety

Crude oil is formed as a result of accumulation of animals and plants that died millions of years ago and fell to the bottom of the sea. These remains were covered by mud, which eventually became rock, thus forming a seal. The rock exerts pressure on the dead animals and plants, thereby generating heat between 60-120$^0$ C [10]. Together, the heat and the pressure in the absence of oxygen turned the remains into crude oil. However, if the trapped organic matter is heated to temperatures greater than 120$^0$ C gases are formed [11] which are either toxic or combustible [12]. As a result of this process, many accidents have occurred in several industry fields, one notable example is the, ExxonMobil fire incident on 18$^{th}$ February 2015 in Torrance, California [13]. In this incident, a massive explosion took place in ExxonMobil oil refinery, which injured four workers and led to considerable damage to the refinery. The incident happened while a maintenance worker was doing his job making an ignition near a leakage of gas. Another gas related accident took place on April 20th, 2010 in the Gulf of Mexico. In this incident, eleven workers died and several others were injured due to a blowout as a result of several "kicks" on the Deepwater Horizon oil rig [14]. A kick is a sudden and unplanned release of well fluids (especially gases) into a wellbore [15]. It was found that these accidents were either due to the total absence of gas sensors in operation sites or the lack of their continuous presence (throughout the time of operation) in the area [16]. In an effort to avoid such accidents, safety measures to curve the risk of gas related accidents have been recommended by United States Chemical Safety Board (USCSB) [17] and regulations are passed by Occupational Safety and Health Administration (OSHA) [18].

## 1.2 Objectives:

The goal of this research is to find an efficient wearable senor network for monitoring toxic and combustible gases that cause a serious risk to both human beings and the environment. A number of objectives are listed as follows:

- Implementation of a wearable gas sensor network using gas sensors, Arduino microcontroller, and XBee wireless communication module.
- Early warning messages to be sent to workers for toxic gases before it reaches its low danger level.
- Developing a system that can be able to pinpoint a missing worker.
- The system provides many features: flexibility, cost effectiveness, and low maintenance.

## 1.3 Contribution of the research

- A wearable sensor network with wireless communication can accurately measure toxic and combustible gas around individuals and send warning messages to other workers.
- A modified version of MQ-7 sensor to sense Carbone Monoxide (CO) and methane (CH4) instead of CO only, depends on the sensitivity characteristics of the sensor.
- 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.

## 1.4 Thesis organization

Chapter 2 describes literature review of state-of-the-art gas detection systems that other researchers have developed. Chapter 3 provides the requirements for implementation of a wearable system and wireless communication technologies which are used in oil and gas industries. We also cover the industrial gases and sensors types that are suitable for detecting toxic gases. Chapter 4 outlines overall system architecture and the system hardware and software design. In chapter 5, explanation of experiment setup and results are presented. Chapter 6 gives a summary of the entire thesis work and potential for future development respectively.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

Recently, there has been a common trend in implementing sensors in order to improve environment safety and control of gases [19]. Engineers prefer wired systems to Wireless Gas Sensor Network (WGSN) [20] due to the fact that they are reliable and they can provide abundant resources, such as energy and bandwidth. However, wired systems have some drawbacks, most notable that their installation is costly in terms of time, money and manpower (all of which are not taken for granted in the Oil and Gas Industry). Also, during relocation (e.g. in oil exploration), a huge man-power is needed to remove and transport the system to a new location, where it will have to be installed again and finally, wired methods are impractical in some applications. Recent development in wireless technology have allowed for the reliable use of wireless communication in the noisy industrial environment. Zigbee (IEEE 802.15.4) is one such developments certified for industrial sensing and diagnostic applications [21]. This paves the way for different kind of WGSN applications.

In this chapter, state of the art designs and research breakthroughs of other researchers in the WGSN are analyzed, in the hope of finding a perfect WGSN solution that complies with industrial standards.

## 2.2 Literature review

For the current growth in ubiquitous computing and communication, wearable sensors technologies are getting more attention and more research [22][23] has been done in such fields like healthcare [24], safety [25], and environment [26]. As a result, wearable sensors can assist to save human lives [27] and monitor environmental issues. Forsyth et al [28] 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. As the power supply is 9V and the Xbee module operates at 3.3V, the system contains an Xbee explorer. The system uses simplex method of transmission (from the Xpod module to the Xbee coordinator receiver), which means users have limited or no control over it. Also, the measurement was affected by the movement of the sensor so that the results sometime are not accurate.

Nikzad *et al* [29] presented a wearable devices (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 [30]. Similarly Fletcher *et al* [31] developed a device (Eco-Mini) to sample and record variety of environmental parameters (Ozone, Sulfur Dioxide, Volatile Organic Compounds, humidity, temperature, ambient light color balance, and sound level). The device contains Atmel Xmega 128K with (12-bit ADC) and SPI/I2C ports to communicate with sensors. Also 3-axis accelerometer was used to indicate that the Eco-Mini devise was worn and also for more accurate estimation for air pollution exposure. A global position system (GPS) was deployed to determine the location with an external circuit to reduce power consumption. In addition, to collect data, a Bluetooth module was used to send measured data to mobile phone or stored into SD card for data logging. Moreover, a mobile application was developed to provide simultaneous data on the mobile phone via Bluetooth and a web server for further processing and to display previously collected data. Hu *et al* [32] developed a mobile application that exploits the air pollution data which comes from wearable sensors and human activity energy to estimate the personal inhalation dosage of air pollution.

Heurtefeux et al [33] designed a system for monitoring workers who work in harsh environments. Shimmer's [34] wearable device was used as a sensor node to monitor the state of wearer, and the gateway constructed of many devices like beagle board XM [35], touch screen, wireless communication module (WiFi 802.11 and Zigbee 802.15.4). The sink (network coordinator) has a large data storage which allows it to be able to collect data from different workers. Again Wang *et al* [36] developed a portable device that can be used to monitor electricity workers. The device contains pulse and temperature sensors with Zigbee module and 8-bit ATmega128L microcontroller. The system does not have relay nodes and a front-end amplifier RFX2401C was added in order to increase the transmission range of the Zigbee module. However, this amplifier consumes a lot of energy which could affect the life time of the sensor which was not mentioned.

In [37] Senyureket al were concerned with increasing the safety of workers who worked alone through a wearable transceiver including movement sensor. The system operates when there is no movement or excessive activity. A ZigBee network was used and it consists of the following: a wearable device that is constructed of accelerometer (MEMS) integrated with digital output, MSP430F2618 Microcontroller to monitor the wearable sensor component, Zigbee wireless communication module, LEDs, buzzer, and vibrator. Second is the relay node or router, which is responsible for extending transmission range between the wearable sensor and network coordinator by relaying traffic between the two. The third is the gateway device which serves as a bridge between the Zigbee network and a workstation and oversees the operation of the network. As the sensor comprises of only a movement sensor, it will be susceptible to give false alarms. In order to increase the accuracy of the system, many sensors should be added to indicate the exact situation of the worker and the surrounding environment

Air pollution is considered to be one of the important parameters that affects the ecosystem as well as impacts on human health. A variety of methods have been conducted to monitor harmful gases into atmosphere. For example Manes *et al* [38] 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. The coordinator forwards the data of VOCs sensors and climate sensor to a remote web server for further processing through Ultra High frequency (UHF-ISM) and GSM module for internet connection. However, Photoionization Detectors consumes a large amount of power, so that it will be difficult to replace batteries or using another power supply for the end nodes in a harsh environment. The authors tackled this problem by using a hybrid communication of wire and wireless where the VOCs detector were placed in a dangerous area and the power supply was located in a safe zone [39]. Mead *et al* [40] developed a system with static

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