



UNIVERSITI PUTRA MALAYSIA

***GAS INSPECTOR MOBILE ROBOT AS CARBON MONOXIDE
SOURCE FINDER***

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GAS INSPECTOR MOBILE ROBOT AS CARBON MONOXIDE SOURCE FINDER

By

SARAH REZAEIAN

**Thesis Submitted to the School of Graduate Studies, Universiti
Putra Malaysia, in Fulfilment of the Requirements for the Degree of
Master of Science**

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DEDICATIONS

In dedication to my beloved ones for making me be who I am,
my parents, my only sister, and my best friend Hamidreza
for their support and encouragement in all ways.



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

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By

SARAH REZAEIAN

July 2015

Chair: Assoc. Prof. Mohd Nizar b Hamidon, PhD
Faculty: Engineering

By increasing the production and emission of chemical compounds and toxic gases due to development of cities, industries and technology, control and monitoring the environment in order to prevent the emissions of hazardous air pollutants have become one of the most important issues that have been conducted. If there is any toxic gas present in the environment, it has to be detected and its source must be localized. Fire is one of the most possible and common disasters, which in many cases occurs accidentally and produces a large portion of toxic gases and smoke, and threatens the environment's safety and human's life. Therefore there have been great attentions to fire-related issues including fire detection, localization and extinguishing. Although significant improvements in fire detection systems provide more reliable and faster detection, which is very effective to control the damage at early stages of fire, still localizing the source of fire is a dangerous process, which is primarily done by human operators with high life-threatening risks. Various intelligent mobile systems are proposed for this application but they mostly operate according to the visible characteristics of fire, which in many potentially harmful circumstances like smouldering, they could fail. As carbon monoxide is one of important components of every type of fire and presents in every stage of combustion and doesn't exist in ambient air, it can be considered as a reliable target gas to localize fire source. In this project an inspector mobile robot is implemented to localize fire as a CO source, and a novel searching strategy including a sensing unit and a searching method is proposed. For sensing unit, an array of three different kinds of semiconductor sensors of TGS series are used to detect the CO, which are inexpensive and commercially available. Experiments of sensing unit show the ability of this structure to estimate the source location in right, left, front or back side of robot. Navigation of this robot is based on the gas concentration in environment by air sampling in regular intervals. Algorithms used for exploration and localization by mobile robots are mostly been developed to run on a PC, so they are not

executed in real-time. Using FPGA is proposed by related works as a solution to have complex computations done in a single chip without the need for an external processing unit and to speed up the localization process. Therefore, Altera Cyclone II FPGA was used as the main processing and control unit because of its availability in the research lab. This robot could localize and declare the CO source successfully in 80 percent of experiments.



Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

GAS ROBOT UNTUK MENCARI MUDAH ALIH SUMBER KARBON MONOKSIDA

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Dengan meningkatkan pengeluaran dan pelepasan sebatian kimia dan gas-gas toksik disebabkan oleh pembangunan bandar, industri dan teknologi, kawalan dan pemantauan alam sekitar untuk mengelakkan pelepasan pencemar udara yang merbahaya telah menjadi salah satu isu yang paling penting yang telah dijalankan. Jika ada mana-mana gas toksik yang wujud dalam persekitaran, ia perlu dikesan dan sumbernya mesti dikenalpasti. Api adalah salah satu bencana yang paling mungkin dan biasa berlaku dan dalam banyak kes berlaku secara tidak sengaja dan menghasilkan sebahagian besar gas toksik dan asap, dan mengancam keselamatan alam sekitar dan kehidupan manusia. Oleh itu terdapat perhatian yang besar kepada isu-isu yang berkaitan dengan kebakaran termasuk pengesanan kebakaran, penyetempatan dan pemadam. Walaupun peningkatan yang ketara dalam sistem pengesanan kebakaran membolehkan pengesanan yang lebih dipercayai dan lebih cepat, yang mana sangat berkesan untuk mengawal kerosakan di peringkat awal kebakaran mengenalpasti sumber api adalah satu proses yang merbahaya kerana ianya dilakukan oleh pengendali manusia yang mengancam nyawa. Pelbagai sistem mudah alih pintar yang dicadangkan untuk aplikasi ini tetapi mereka kebanyakannya beroperasi berdasarkan ciri-ciri kebakaran yang boleh dilihat, yang mana dalam banyak keadaan merbahaya seperti dalam keadaan membara, mereka boleh gagal. Karbon monoksida adalah salah satu komponen penting dalam setiap jenis kebakaran dan wujud di setiap peringkat pembakaran dan tidak wujud dalam udara persekitaran, ia boleh dianggap sebagai gas sasaran yang boleh dipercayai untuk melokalisasikan sumber api. Dalam projek ini robot pemeriksa mudah alih telah dibangunkan untuk mengenalpasti api sebagai sumber CO, dan satu strategi pencarian novel termasuk sebuah unit penerima dan, satu kaedah pencarian adalah dicadangkan. Untuk unit penerima, jujukan tiga jenis pengesanan semikonduktor TGS siri telah digunakan untuk mengesan CO, yang mana ianya murah dan boleh didapati secara komersial. Eksperimen daripada unit penerima menunjukkan keupayaan struktur ini untuk mengangkar kedudukan sumber di sebelah kanan, kiri, depan

atau belakang robot. Navigasi daripada robot ini adalah berdasarkan kepekatan gas dalam persekitaran oleh persampelan udara dalam jangka masa yang tetap. Algoritma yang digunakan untuk penerokaan dan penyetempatan oleh robot mudah alih kebanyakannya telah dibangunkan untuk beroperasi menggunakan PC, maka ianya tidak dilaksanakan dalam masa nyata. Penggunaan FPGA dicadangkan sebagai penyelesaian untuk pengiraan kompleks dalam cip tunggal, tanpa perlunya unit pemprosesan luaran dan untuk mempercepatkan proses penyetempatan. Oleh itu, Altera Cyclone II FPGA telah digunakan sebagai pemprosesan dan unit, kerana ia boleh didapati di makmal penyelidikan. Robot ini boleh berjaya menyetempatan dan mengisytiharkan sumber CO, dalam 80 peratus daripada eksperimen.



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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science.

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CHAPTER 1

INTRODUCTION

1.1 Background of Project

In today's world, with development of cities and significant increase in amount of workshops, manufacturing industries and chemical products, industrial pollution caused by production and emission of chemical compounds and toxic contaminants has become a major concern. Hazardous gases are one of air contaminants, which in an adequate level of concentration can have serious effects on the safety of environment, so, they are required to be monitored in order to be retained under the dangerous level. Investigation of the policies and procedures in order to prevent the emissions of hazardous gases is one of the most important issues that have been conducted in last three decades.

One of the most common sources of toxic gases is fire which, in fact, is a disaster and in many cases occurs accidentally and may cause extreme damage to property and humans' life (Ge et al., 2014). All types of fire contain smoke and toxic gases, which through inhalation and skin absorption, cause serious and fatal effects on people in the fire exposure area, so, fast fire detection as well as accurate fire localization are of main concerns in these research area with the aim of damage control due to the smoke release (Hu et al., 2008).

Heat detectors, smoke detectors, flame detectors and gas sensors are the most generally employed sensor technologies in fire detection systems, which due to their different principal of operations, each type has advantages and disadvantages in various applications and environments (Hangauer et al., 2009). For example, smoke detectors show cross sensitivity to some substances like dust or water vapour, which leads to false alarm. On the other hand except for gas sensors, other detection systems work based on the visible characteristic of the fire like smoke or thermal changes, while slow burning or smouldering, that is a hazard because of producing a high concentration of an important toxics, carbon monoxide, has low heat output and is flameless, which make it hard to be detected by these systems (Jackson and Robins, 1994). Therefore, it seems that among all these detection systems, gas sensing-based fire detection is more reliable, because of presence of toxic gases in every stages of combustion (Nebiker and Pleisch, 2001). Since CO is not supposed to be present in fresh and ambient air, it is a well-known gas to be detected during the fire detection and localization (Hangauer et al., 2009), hence, checking the existence of CO in the environment is an effective way for both poisoning and fire prevention (Zhuiykov, 2008).

Carbon monoxide (CO) is one of main toxic gases which is produced in all types of fire and presents in every stage of combustion and depend on fast or slow burning, its concentration could be low or high respectively (Liu and Kim, 2003). This gas is invisible, tasteless, odourless, poisonous, and lethal. Moreover, this is undetectable to the human senses, which is also called "silent killer". Depending

on its level and length of exposure, it can cause some symptoms such as headache, dizziness, nausea, vomiting and chest pain. Higher level of poisoning can result in permanent brain damage, suffocating and death (Tsai et al., 2014). Relationship between CO concentration, time of disclosure and health effects to a person in the area of exposure is given in table 1.1 (NEMA, 2013).

Table 1.1: Effects of CO disclosure over time

Concentration (ppm of CO)	Time of exposure (Minutes)	Symptoms
50	480	No adverse effects.
200	120~180	Mild headache.
400	60~120	Headache & nausea.
800	45	Headache, nausea & dizziness.
	120	Collapse & loss of consciousness.
1000	60	Loss of consciousness.
1600	20	Headache, nausea & dizziness.
3200	5~10	Headache, nausea & dizziness.
	30	Collapse & loss of consciousness.
6400	1~2	Headache & dizziness.
	10~15	Loss of consciousness & danger of death.
12800	1~3	Immediate physiological effects, unconsciousness & danger of death.

Different types of CO detectors are commonly used to do this task. CO detectors are generally devices composed of gas sensors, control components and an alarm notification appliance in a single unit. Operation power of these devices is from either batteries inside the unit or obtained at the point of installation. They work based on the concentration of CO over time and trigger an alarm immediately when they detect the specific amount of CO (NEMA, 2013). These detectors are available as stand-alone, system-connected and portable models.

Stand-alone models are including single or multiple stations CO detectors. Therefore, they can detect CO and as soon as the level of the gas exceeds safe level, 50 ppm, (table 1.1), an audible signal will alert occupants. Stand-alone detectors need at least one person to be available near the detector to be alerted and have access to the source of CO in order to cut off the source or do any other proper action. Hence, if the place being empty or occupants are not capable of responding to local alarm as they are elders, disabled individuals, small children, or individuals already unconscious due to the CO, this detector seems useless.

System-connected models are CO detectors connected to a dedicated CO control unit or a fire alarm control unit. Task of control unit in this system is to monitor initiating and notification circuits for integrity and send the trouble signals to a remote monitoring location. In the case of CO detection while the place is empty or residents are sleeping or they are already unconscious due to the high level of CO, the remote central station will be alerted and has the capability of

sending proper authorities to investigate the place (McDermott, 2004). System-connected models try to eliminate this problem by monitoring and supervisory the interconnected detectors, so that in such situation central station attempt to alert property owners and send emergency responds in the case of high concentration of CO. However, there maybe unwanted delay in between the time of dispatching emergency team and when they reach to the area which may lead to disaster.

Portable CO detectors are hand-held devices which can be used in any indoor and outdoor area (Brown, 2006) with the advantages of high mobility, low power consumption, no sample preparation, and capability of real time monitoring (Bufaroosha et al., 2013). They are appropriate for professional applications and can be used for manually inspection by individuals or property managers with the purpose of maintain and diagnosis issues like finding the CO emission source. These detectors also have a weakness which is the need for having someone to carry the them and manually search which in fire situation or high concentration of smoke and CO is not safe.

1.2 Problem Statements

Carbon monoxide is lighter than air (Hampson et al., 2012), it will distribute quickly, so, early detection and fast source locating are very important. Although CO detectors are very useful safety devices, they cannot provide a full protection. Stand-alone and System-connected models just can alarm as soon as they detect CO, but can't localize or estimate the source. and as mentioned before portable detectors also need human operation and manually inspection. Therefore, despite importance and danger of fire localization, this task is still mainly done by human operators, which has a high risk of injury or poisoning. It even becomes more dangerous when the environment to be investigated is not easily accessible or concentration of CO is very high.

During last two decades, many researchers studied the different ways of fire fighting tasks including detection, localization and extinguishing with less human operation and attempted to develop new strategies, such as proposing smart detection systems and developing intelligent mobile robots to replace the human in fire localization (Chien et al., 2007). Proposed autonomous mobile robots for this purpose, operate according to the visible characteristics of the fire (temperature, smoke, flame) and there is a gap in research for localizing in the case of smouldering when there is no much visible effects, while with high concentration of CO, it is very considerable and dangerous.

In order to fill this gap, in this thesis, an CO inspection mobile robot is proposed with the ability of CO detecting and tracing, with the aim of using in the fire localization application. So contribution of this research is to propose a new fire localizing strategy by design and implementation of a mobile robot with:

1. A new sensing unit structure

2. A new plum tracing method (searching strategy) for CO source finding

1.3 Aim and objectives of the Study

The aim of this project is to develop a smart mobile robot as an autonomous inspector to localize the CO source after detecting its presence. This is desired to early detection of fire and smouldering as well as to eliminate the role of human in fire localization, as much as possible.

The main objectives of this project are:

1. To develop a gas sensing unit in order to detect CO and determine the source position.
2. To develop a prototype mobile system that employs searching algorithm in order to localize the CO source.
3. To validate the performance of sensing unit and searching algorithm through experimental works.

1.4 Scope and Limitations

There are limitations for this project from the aspects of cost, performance, and efficiency. Therefore this project is limited to develop a single mobile robot equipped with nonexpensive gas sensors calibrated to detect up to 300 ppm which referring to the table 1.1 is the maximum average possible level of CO concentration to release during the experiments before causing serious effects. The total area of experimental environment for CO gas localization was limited to a $160\text{cm} \times 90\text{cm} \times 50\text{cm}$ enclosed environment which can be filled with 300 ppm of CO in an adequate time. More details about the boundary time would be described in methodology, chapter 3. As the focus of this thesis is on the gas sensing for fire localization, no other sensor would be used, so, there is no strong wind and obstacle in the environment and robot moves on a flat ground. It is assumed that there was a constant smooth airflow to create a concentration gradient at the test environment during the experiment.

1.5 Outline of thesis

This masters thesis is divided into five chapters. The first chapter gives an introduction to toxic gases and fire as the most common sources of toxic gases. Then followed by problem statement, aims and objectives, and scope and limitations. The second chapter is including the review of hazardous gases and CO as the major component of fire, mobile robots, sensors and searching techniques in previous studies, and a brief explanation of used techniques and hardware for fabricating this robot. In chapter three an overview of project is given and then the process of hardware implementation and software development of the system are explained. Chapter four focuses on testing the system, results and discussions. In fifth chapter the study is concluded and suggestions for potential future works are offered.

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