Development of Web-based Mobile Olfaction System for Confined Space Hazardous Gas Monitoring

A.H. Abdullah¹, M.A.A. Bakar¹, F.S.A. Saad², S. Sudin², N.H.A. Latif², Z.A. Ahmad³, M. Elshaikh³, K.A. Ismail⁴

¹Faculty of Tech. Eng., Universiti Malaysia Perlis, Perlis, Malaysia
²School of Mechatronic Eng., Universiti Malaysia Perlis, Perlis, Malaysia
³School of Computer & Communication Eng., Universiti Malaysia Perlis, Perlis, Malaysia
⁴School of Manufacturing Eng., Universiti Malaysia Perlis, Perlis, Malaysia
abu.hassan@unimap.edu.my

Abstract. Hazardous gas in the confined space is an issue that often causes danger to the worker while doing the tasks i.e. installation, cleaning and maintenance. The nature of the area may expose the worker to hazardous gas leakage. It is important to monitor the hazardous gas in the surrounding area before the worker start their task inside the confined space. This paper proposes a study of developing a web-based mobile olfaction system for confined space hazardous gas monitoring. The system is integration between a mobile robot and an electronic nose (e-nose). The system will reduce the danger faced by the worker from the hazardous gas. The e-nose consists of a sensor array, embedded controller, electronic components and wireless GSM communication. The instrument sensors i.e. hydrogen sulphide, oxygen, carbon monoxide and methane are used to acquire the confined space air sample. It will also acquire the environment temperature and humidity. The robot which piggyback the instrument will manoeuvre through the environment while acquires data. The data acquired were transmitted and monitored wirelessly to the web-based information system. The website layout is designed using HTML and JavaScript. Data received from e-nose will be stored into a database, MySQL server before being process by the website. The data will go through the conversion process from digital value to PPM. Then the data will be classified using ANN to obtain the Hazardous Gas Concentration Index (HGCI). The website will display the HGCI mapping of the area in real-time. Results show that the system performance is good and can be used to monitor the hazardous gas in the confined space.

Keywords—Electronic Nose, Mobile Olfaction, Confined Space, Hazardous Gas, Web-based Information System.

1. Introduction
The maintenance worker that required to work in confined space i.e. pipeline inspection, repairing utility holes, silo, manholes, tunnels, cave, sewers etc. is dangerous when expose to hazard environment. The area limited space and poor ventilation will affect the worker health while perform the specific task such as installation, cleaning and repairs. The place also vulnerable to serious injuries from expose to hazardous gas i.e. carbon monoxide, hydrogen sulphide lack of oxygen methane and flammable gas. These may arise from the work that being carried out by the worker such as welding or machine operation. So, it is useful to have a system that able to monitor the hazardous gas in the confined space for the safety of the worker.
Olfaction is also being used by animal to avoid dangerous situations or warn the presence of predators. Currently olfaction technique that being used by dogs to detect drug, explosive, escape prisoner, victims of earthquake and gas leakages. Dogs required extensive training and care by expert handlers. Dog attention also short, can easily divert and suffers from fatigue [1]. It’s also exposing to the hazardous environment that that will affect it safety and health. Existing research on olfaction are mainly on navigation algorithm on odour detection, source localization and its distribution. The techniques that had been used to detect odour source are such as trail following, plume tracking and localization [2]. To date, the research on olfaction have concentrated mainly in the application of environmental monitoring [3].

The combination of electronic nose (e-nose) and mobile robot called mobile olfaction. In indoor environments, the system could be used to prevent toxic fumes poisoning caused by fire or to mark the areas that are already covered in floor cleaning applications. Metal-oxide (MOS) gas sensors were used in most of the system because of their high sensitivity, compact size and fast response time [4]. The system can be used as the alternative to perform similar tasks with less supervision and more reliability. The system’s flexibility and ability to manoeuvre in difficult and isolated areas is important for the safety of humans in the area especially without adequate safety procedure [5]. Therefore, this project has aimed to develop a web-based mobile olfaction system to monitor hazardous gas for confined space application [6]. The web-based information system is used to remotely monitor the hazardous environment for the worker safety and health. The system will able provide safety measures for the worker while perform specific task in the confined space.

2. System Description
The web-based information system architecture is shown in Figure 1 where the e-nose is piggyback on a mobile robot. The e-nose data sampling process is most effective when its front-end position facing the hazard environment [7]. The e-nose acquired data will be transmitted wirelessly to a using a GSM communication module. The system will process and analyse the acquired data, then it will display the finding in website.

![Figure 1. The Mobile Olfaction System.](image)

2.1 Electronic Nose
The e-nose is developed to mimic the human sense of smell, comprises of an array of sensors, sensing chamber, embedded controller, electronic component and pattern recognition system. The instrument is capable of discriminating the sensor signals into classes corresponding to the pollutant i.e. hazardous gas fingerprint [8]. The instrument is piggyback on a mobile robots that have advantages over conventional methods [9]. The instrument as shown by Figure 2 others components are sensing chamber, embedded controllers board as well as electronic circuit and DC power supply. The instrument is using selected MOS gas sensors i.e. oxygen, toxic gas and explosive gas as shown in Table 1. The sensors were used because of their high sensitivity, compact size and fast response time [10]. A humidity & temperature sensor was also being attached to the instrument enclosure to monitor the environment condition. The instrument uses a dsPIC33 microcontroller as its embedded controller [11]. The instrument sensing chamber material and enclosure was selected to withstand sensor heater high temperature. The headspace sampling system will deliver the air sample to flow properly into the sensing chamber which ensures all sensors exposure to the air sample effectively. An air-pump was used to draw-in the sample to chamber during Sniff cycle and for purging cycle it will flush out sample
from the sensing chamber. The embedded software was also used to communicate with the web-based information system through GSM communication.

| Gas Type          | Human Limit       | Sensor Sensitivity |
|-------------------|-------------------|--------------------|
| Oxygen            | 15 – 19 %         | 0 – 30 %           |
| Carbon Monoxide   | 35 ppm            | 10 – 300 ppm       |
| Hydrogen Sulphide | 5 ppm             | 1 – 100 ppm        |
| Methane           | 1000 ppm          | 300 – 10000 ppm    |

**Figure 2.** The Electronic Nose

2.2 *Mobile Robot*

The mobile robot shown in Figure 3 is used for the e-nose to move across the area. The chassis is made from aluminium plate and its size is 40 cm wide, 50 cm long and 30 cm high. It’s uses PIC18 microcontroller and embedded software was developed to control the navigation. It’s also equipped with remote control for manual mode. Three ultrasonic sensors were situated at the front-end to determine the distance between robot and obstacles. Its will used information from these sensors to manoeuvre inside the confined space.

**Figure 3.** The Mobile Robot

2.3 *Web-Based System*

Internet of Things (IoT) system is a wireless communication network that has consisted of sensor that has connected to the Internet. Whereas, Web of Things (WoT) is defined as create IoT that is built with website technology [12]. The web-based information system which used the WoT is being applied by collecting, process, analyse and display the finding about data from the environment by using website [13]. The system website will monitor the confined space atmospheric environment and
alert the user for any hazard condition. The website development can be divided into four parts as show in Figure 4. Data collection from the e-nose is transmitted wirelessly using GSM module to web server and saving it in database. The data will be converting from digital value to Part per Million (PPM). Then the data will be classified using Artificial Neural Network (ANN) to obtain the location Hazardous Gas Concentration Index (HGCI). After that the system will display the environment HGCI on the website as graphic representative.

This mapping system will show the location points in the area with the HGCI. The area hazard condition is being displayed and monitor by the website in real time. The web-based information system is also trained to recognize, by different sets of measurements, hazard patterns for different polluting factors acting in the monitored environment, as well as identify accidental patterns of the hazardous gas.

Figure 4. The Web-based Information System

The coding for develop the web-based information system is by using XAMPP software. It contains HTML it is a standard mark-up language to create web pages and web applications [14]. The PHP language an open source general-purpose scripting language for the web development is also embedded into HTML [15]. The MySQL software is an open source relational database management system (RDBMS) based on Structured Query Language (SQL) is used for acquired data storage[16].

Then the data will be converts from digital values to PPM for standard gas measurement unit. Every sensor has different formula for sensor resistance, Rs and the value of sensor resistance in clean air, Ro according to the respective sensor. First step is to determine the value of gradient, m by using a formula in equation (1). The number for y and x is taken from the graph in a datasheet according to the respective sensor. The value for k can be found by choosing any number of y and x to put inside the formula in equation (2). To find the value for y, need to determine the value of Rs by using a formula and the value of Ro that has been given in a datasheet. The value of PPM has been calculated according to the formula given in equation (3) and equation (4). Lastly, the PPM in percentage is calculated by using equation (5).

\[ m = \frac{\Delta \log y}{\Delta \log x} \]  
\[ k = \frac{y}{x^n} \]  
\[ y = \frac{R_s}{R_o} \]  
\[ x = 10^{\log(\frac{y}{k})} \]  
\[ x_{ppm} = \frac{x_{ppm}}{10000} \]
Where, Rs is sensor resistance at gas various concentration, Ro, sensor resistance in clean air, k,y value that cross line x and m, slope of the line.

After that the data were analysing by using ANN for its good adaptability property (learning, generalisation and noise tolerance) which is suitable for the non-linear data. It has the ability to learn the complex interaction between the malodour sample variables [17]. The Multiple Layer Perceptron (MLP) ANN model is used to generate the HGCI which being test for classifier success rate. It will generate the HGCI based on air sample of each location. All of the results indicate that the tests classifications correlate with sample location. The results show that the mobile olfaction system was able to generate the HGCI according to their location. The system performs good and fast measurement, processing and transmission of the sample data. It is very useful that the web-based information system able to monitor hazardous gas in the confined space.

3. Methodology
An experiment was conducted to verify the e-nose sensitivity and detection limit that correlate with the hazardous gas concentration. The samples were collected in a hospital basement room in Malaysia. The process was conducted on-site at four different locations in the environment. The samplings process is illustrated in Figure 5.

![Confined Space](image1)
![Mobile Olfaction](image2)
![Sensor Response](image3)

**Figure 5.** The Sampling Process

The e-nose sampling process utilise the Purge *Sniff and Hold* technique whose parameter settings are shown in Table 2. Initially the instrument is being Purge using active carbon to clean the sensors before start to sniff the air sample. Then it will acquire the baseline air sample data before sniffing at four specific locations in the area. The robot will move to per-set location before the sniffing process being repeated. This technique will *pre-concentrate* and *Hold* the air sample to enhance the instrument sensitivity. The duration of the instrument process cycles is based on the MOS sensor characteristics and *trial and error* [10]. Then the instrument will send the acquire air sample wirelessly to the web server through GSM module.

| Table 2. The Electronic Nose Sampling Parameter |
|-----------------------------------------------|
| Operation          | Time (Sec) | Air Pump |
| Purge Cycle        | 10         | ON       |
| Baseline           | 30         | OFF      |
| Sniff Cycle        | 10         | ON       |
| Steady State       | 30         | OFF      |
4. Results and Discussion

4.1 Sensor Response
The sensor response was a time series of waveform profiles as shown in Figure 6. The sampling technique was suitable because the acquired data were within the measurement range. This indicated that the e-nose functions accordingly to different sampling location. The acquired data was being pre-process by applied filtering and baseline manipulation. Relative baseline is used by comparing the ambient with the sample air. This process will improve the system sensitivity which will enhance the classification result.

![Figure 6. The Electronic Nose Sensor Response](image)

4.2 Web-Based System
The data acquired from the location is transmitted wirelessly by GSM to the web server. MySQL software is used to build a database to store the received data. Hypertext Mark-up Language (HTML) and JavaScript have been used in order to design the website and analyse data from MySQL server. The digital data will be retrieved and convert to PPM as shown in Table 3.

| Hazardous Gas        | Loc. P1 | Loc. P2 | Loc. P3 | Loc. P4 |
|----------------------|---------|---------|---------|---------|
| Oxygen               | 21%     | 20.9%   | 20.9%   | 21.3%   |
| Carbon Monoxide      | 0.29    | 0.25    | 0.26    | 0.27    |
| Hydrogen Sulphide    | 2.13    | 2.97    | 3.37    | 3.32    |
| Methane              | 114.27  | 114.50  | 114.02  | 114.33  |

The Multilayer Perceptron (MLP) is used to generate the HGCI ANN model. The model used 70% of the data for training and 30% for testing. The output will be set in between 0.0 to 1.0. Table 4 shows the HGCI colour coding.

| Colour | Concentration Index | Condition         |
|--------|---------------------|-------------------|
| Green  | 0 – 0.20            | Very low - excellent |
| Brown  | 0.21 – 0.30         | Low – good        |
| Light  | 0.31 – 0.39         | Medium - normal   |
| Blue   | 0.60 – 0.70         | Very high - danger|
| Yellow | 0.40 – 0.59         | High - caution    |
| Red    |                     |                   |

Table 3. Conversion from Digital to PPM

Table 4. Hazardous Gas Concentration Index Colour
The developed system website is shown in Figure 7. HGCI at each location will be arranged in graphic representation as shown by webpage in Figure 8. The website will show oxygen, carbon monoxide, hydrogen sulphide, methane and overall in rotational order for every 10 second interval. The HGCI location is represented by five different colour code that give different information about hazardous gas in the area as shown by Table 4.

![Figure 7. Mobile Olfaction System Website.](image)

![Figure 8. The Webpage Layout.](image)

5. Conclusion
A mobile olfaction system prototype using an e-nose integrate with mobile robot for navigating inside the confined space has been successfully developed. The system was tested to acquire air samples and transmitted wirelessly to website using GSM communication module. The web-based information system for monitoring the hazardous gas was developed by using HTML and JavaScript. The real time data collection is MySQL, the conversion from digital to PPM and the HGCI was generate using ANN model. The HGCI of oxygen, carbon monoxide, hydrogen sulphide and methane were displayed by the website. The environment parameter i.e. temperature and humidity also being display. The system also able to send alert signal once the HGCI exceed the safety value. Future work should consider the used of fuzzy logic for the uncertainties in generating the HGCI.

Acknowledgement
This research work is partly funded by the Ministry of Science, Technology & Innovation of Malaysia under the Science Fund Grant Scheme (Project No: 9005-00066). The author also gratefully acknowledges to Universiti Malaysia Perlis (UniMAP) for the opportunities given to do the research.
References

[1] Elise Hancock 1996 A Primer on Smell: A Special Issue on the Senses, (Johns Hopkins Magazine, Baltimore, USA)

[2] Hayes A T, Martinoli A and Goodman R M 2001 IEEE. Intl Con. Intelligent Robots and Systems 1073

[3] Gardner J W, Persaud K C, Gouma P and Osuna R 2012 Sensors Journal vol. 12(11) 3105

[4] Sandini G, Lucarini G, and Varoli M 1993 IEEE/RSJ Int. Conf. on Intel. Robots System Proceeding 429

[5] Pearce T C , Schiffman S S, Nagle H T and Gardner J W 2003 Handbook of Machine Olfaction: Electronic Nose Technology (Wiley-VCH Germany)

[6] Ishida Wada and Matsukura, 2012 IEEE Sensors Journal 12(11) 3163

[7] Loutfi A 2006 Odour Recognition Using Electronic Noses In Robotic And Intelligent Systems (PhD Thesis Örebro University Sweden)

[8] Gardner J and Bartlett P 1994 Actuators B 18(1) 211

[9] David M 2014 Robot, Control, and Sensing (Craver Dissertation)

[10] Figaro Engineering 2005 General Information for TGS Sensors Online: http://www.figarosensor.com/ product/common(1106).pdf

[11] Microchip Technology 2007 High-Performance 16-bit Digital Signal Controller, Online: http://freedatasheets.com/downloads/dsPIC33FJXXXMCX06X08X10dsPI CDSC

[12] Diaconescu I M and Wagner G 2015 Con. On Multiagent System Technologies 9433 137–153

[13] Sim S and Choi H 2017 Journal of Cluster Computer 21(1) 1151-1160

[14] Yadav P and Barwal P N 2014 Int. Journal Sci. Tech. and Research 3(11) 152-155

[15] Bolboacă S, Jäntschi L, and Cadariu A A 2003 Leonardo Electronic Journal of Practices and Technologies 2(2) 2 37-52

[16] Ya N, Zainuddin A, Fatinah I, Abidin Z, and Yusof A L 2016 IEEE Int. Con. on Control System, Computing and Eng. (ICCSCE) 25

[17] Khong M D, Gale T J, Jiang D, Olivier J C, and Ortiz-Catalan M 2013 Biomed. Eng. Int. Conf. 1