MODELLING THE RESPONSE OF DIFFERENT MOX GAS SENSOR IN VARYING AMBIENT TEMPERATURE AND HUMIDITY

by

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LIST OF ABBREVIATIONS

ANN	Artificial Neural Network
CP	Conductive Polymer
CV	Cross Validation
MLP	Multiple Linear Regression
MOX	Metal Oxide
MSE	Mean Square Errors
PCB	Print Circuit Board
PID	Photoionization Detector
PLS	Partial Least Square
TWA	Time Weighted Average
VOC	Volatile Organic Compound

LIST OF SYMBOLS

P_{error}	Percentage Error of Gas Response
R_a	Sensor Resistance in Presence of Ambient Dry Air
R_H	Relative Humidity
R_H	Heater Resistance
R_L	Load Resistance
R_S	Sensor Resistance
V_C	Voltage Supply
V_H	Voltage Heater
V_L	Voltage Across R_L

Memodelkan Tindak Balas Penderia Gas MOX yang Berlainan dalam Suhu dan Kelembapan Persekitaran yang Berubah

ABSTRAK

Penderia gas logam oksida (MOX) adalah salah satu teknologipenderia gas yang telah digunakan secara meluas dalam pelbagai aplikasi. Dalam beberapa dekad, penderia gas MOX telah digunakan untuk pemantauan gas kerana kelebihannya seperti kepekaannya yang tinggi, julat pengesanan yang tinggi, masa reaksi yang cepat dan menjimatkan kos. Walau bagaimanapun, penggunaan penderia gas MOX masih terhad kerana beberapa faktor yang mempengaruhi kemampuan penderiaannya, seperti komposisi kimia, suhu oerasi, suhu persekitaran dan kelembapan. Penyelidikan ini mengkaji kepekaan silang penderia gas terhadap suhu dan kelembapan persekitaran. Papan PCB dibangunkan mengandungi penderia suhu dan kelembapan, serta lapan penderia gas MOX yang berbeza Selain itu, kebuk separa tertutup juga dibangunkan untuk membolehkan udara masuk dan keluar untuk pengawalan suhu dan kelembapan persekitaran. Penderia didedahkan kepada pelbagai tahap suhu (dari 16˚C hingga 30˚C) dan kelembapan (dari 75% hingga 45%) yang relevan dengan persekitaran dalaman yang normal. Pada setiap tetapan parameter ini, tindak balas penderia gas dicatat secara berterusan terhadap kepekatan gas etanol yang berbeza (iaitu 0%, 0.05%, 0.2%, 0.5%, 1% dan 2%). Berdasarkan hasil ujikaji, terbukti bahawa tindak balas penderia gas dipengaruhi oleh suhu dan kelembapan. Peningkatan suhu dan tahap kelembapan menyebabkan penurunan tindak balas penderia gas untuk kebanyakan penderia, kecuali MiCS-6814 (penderia NH_3) yang menunjukkan tindak balas yang berlawanan. Beberapa model pendekatan pembelajaran mesin berasaskan regresi linear telah dihasilkan untuk memperbaiki arus tindak balas penderia gas. Model-model tersebut disahkan dengan teknik K-fold pengesahan bersilang (CV) untuk mengukur ketepatan calon model berbanding data eksperimen. Akhirnya, model yang paling sesuai disahkan dan terbukti dapat meminimumkan kesan tindak balas semua penderia gas terhadap suhu dan kelembapan. Sebagai tambahan, model yang dicadangkan dalam penyelidikan ini juga dapat diterapkan pada penderia gas MOX yang lain.

Modelling The Response of Different MOX Gas Sensor in Varying Ambient Temperature and Humidity

ABSTRACT

Metal oxide (MOX) gas sensor is one of the technology that has been widely used in different applications. For decades MOX gas sensor has been used for gas monitoring due to its advantages, such as high sensitivity, high detection range, fast reaction time and cost-effectiveness. However, MOX gas sensor has limitation in several factors that affect the sensing ability, such as chemical composition, operating temperature, ambient temperature and humidity. In this research, the cross-sensitivity of the gas sensors toward ambient temperature and humidity. PCB boards were developed, which consists of temperature and humidity sensors, as well as eight different MOX gas sensors. Also, a partially closed chamber was fabricated to allow inflow and outflow of air for the ambient temperature and humidity control. The sensors were subjected to various temperatures (from 16˚C to 30˚C), humidity (from 75% to 45%), which are relevant to typical indoor environment. At each of these parameter settings, the gas sensor responses were continuously recorded at different ethanol gas concentrations (i.e. 0%, 0.05%, 0.2%, 0.5%,1% and 2%). Based on the results, it was proven that the gas sensor responses are affected by the temperature and humidity. The increase of temperature and humidity levels lead to the decreased of gas sensor response for most of the sensor, except for MiCS-6814 (NH_3 sensor) which showed the opposite response. Linear regression based on machine learning approach was applied to correct the gas sensor response drift by producing several models. The models were validated by the technique of K-fold Cross Validation (CV) to provide the measure of fit to the candidate models with respect to the experimental data. Finally, the best fit model was verified and proven to be able to minimize the sensor response drift due to temperature and humidity for all gas sensors. In addition, the model proposed in this research can also be applied to other MOX gas sensor of the same type.

CHAPTER 1 : INTRODUCTION

1.1 Background

Gas sensor system has been implemented in many applications such as monitoring indoor and outdoor air quality, in the chemical industry and in gas leak control system (Ab Kadir et al., 2014). Nowadays, the development of gas sensor technology increases proportionally with user needs. Several researchers have been working on the design of gas sensor system to improve effectiveness and reliability of the devices for detection of target gas (Hu et al., 2019). Numerous toxic gases are present in the environment which can cause serious harm to human. The existence of the toxic gases in atmosphere is due to the lack of awareness of gas emissions or leakages from the industry. The inhalation of these types of gases may cause various health problems, such as lung disease, lung cancer, heart attacks, strokes and death (Niall, 2016).

Volatile organic compound (VOC) can be listed as one of the main pollutants that exist in the atmosphere, which can lead to the formation of mists (Arroyo, 2018). VOC compounds can be found in many household items and easily vaporize at room temperature and pressure which will lower the level of indoor air quality. For example, cleaning reagents that are used in daily activities is the major source of ethanol gas indoors (Al horr et al., 2016). Hence, it is important to perform indoor air quality monitoring to track the quality of the air.

The most commonly used gas sensor in gas monitoring is metal oxide (MOX) gas sensors due to the simplicity of the design, longer lifetime, high sensitivity and lower price (Arroyo, 2018). However, they suffer from response drift and are strongly impacted by ambient conditions such as temperature and humidity (Burgués and Marco, 2018). Sensor drift can be defined as the temporal shift on the gas sensor response at a constant operating condition. This is due to the interferences on the sensing layer and therefore affecting the gas sensor sensitivity. However, to enhance the accuracy and reliability of MOX gas sensors, a new model can be developed to reduce their response drift, especially due to temperature and humidity. Also, the improvements in the gas sensor module is expected to ensure the safety for human health and able to measure a target gas.

In addition to the problems above, MOX gas sensor has limitations in sensing and responding to the target gases that are present in the environment. Liu et al. (2018) discussed on the drawbacks of the MOX gas sensor, when they suffer from response drift and impacted by ambient temperature and humidity. The sensor response may also drift due to the interfering of coexisting molecules in ambient air.

The main working principle of MOX gas sensor is based on redox reaction that takes place on the surface of its sensitive layer. However, temperature and humidity of the ambient air can affect this reaction. Hence, the cross-sensitivity of the MOX gas sensor toward ambient temperature and humidity was studied to improve the performance of the sensor's responds (Kamarudin et al., 2015). The gas sensor's responds were analyzed by using a three-dimensional modeling method, where the data was interpreted in the 3D linear regression (Haugen et al., 2000).

After that, this research was carried out to characterize and model the sensitivity of the MOX gas sensors, as well as the effect of ambient temperature and humidity on their responses. This study aims to develop a model to eliminate drift of different MOX gas sensor response over varying humidity, and temperature in different concentration of target gas.

1.2 Problem Statement

MOX gas sensors are able to detect the presence of the target VOCs (including toxic ones) based on the reaction occurring on its sensing layer. The layer's temperature is usually kept between 200°C – 500°C to improve the detection efficiency of the gas sensor (Ab Kadir et al., 2014; Ponzoni et al., 2017). However, the temperature of the layer might be affected by the changes in the ambient temperature, hence affecting the gas sensor response. This complicates the ambient temperature correction as the relationship between surface temperature and ambient temperature is not constant when the output temperature of the layer differs over time (Masson, Piedrahita and Hannigan, 2015).

Also, the existing water molecule in the environment can be adsorbed onto the layer's surface, resulting in the decrease surface area responsible for chemical reaction between the target gas. Therefore, higher levels of humidity will lead to the reduction in accuracy and sensitivity in sensing target VOCs. Lower levels of humidity normally results in higher accuracy and sensitivity since more chemical reactions can take place on the surface of the sensing layer. The level of humidity thus, affects the adsorption rate and consequently the sensitivity and the baseline of the sensor response will be modified (Wang et al., 2010; Blank et al., 2016).

1.3 Research Question

1. How can sensor drift due to the change in ambient temperature and humidity be monitored?

2. How significant is the effect of temperature and humidity to the response and sensitivity of different MOX gas sensor?

3. How to rectify the gas sensors response drift due to ambient temperature and humidity through model generation?

1.4 Objectives

The main objective of this research is to study the effect of ambient conditions, toward the response of the gas sensors in varying gas concentration. The sub-objectives are as follows:

1. To design and develop gas sensors modules for measuring different MOX gas sensors response, temperature and humidity of the ambient air.

2. To investigate the effect of temperature and humidity on different MOX gas sensors and compare the collected responses between the sensors.

3. To perform 3D linear regression modelling and validation to minimize the gas sensors response drift due to ambient temperature and humidity.

1.5 Research Scope

This project is concerned with minimizing gas sensor response drift due to ambient temperature and humidity. MOX gas sensors are used because it has been proven to have a good accuracy, response time, stability, durability, maintenance, cost and suitability to portable instruments as further discussed in Section 2.3. In this research, eight different models particularly (MiCS-5524, CCS803, GM-402B, GM-702B, GM-502B, TGS-2600, TGS-2602 and MiCS-6814) are utilized. The sensors were selected based on the target gas and suitable concentration range as described in Section 3.3.1. Furthermore, all experiments are restricted to indoor environment with variable temperature and humidity settings.

The gas used in all gas sensors response experiments is ethanol. Ethanol is a volatile organic compound that is easily available and least harmful to human. The handling as well as exposure to ethanol during the experiment is also safe (Al horr et al., 2016). The permissible limit exposure of time-weighted-average (TWA) for ethanol concentration is 1000 ppm (OSHA, 1992).

In previous researches, the gas sensor was typically exposed directly to the ambient air, instead of a closed chamber. However, in this research, a partially closed chamber will be designed and used as an enclosure for the sensing module. The chamber is placed inside an incubator that provides temperature and humidity control.

The calibration of the gas sensor in measuring the actual gas concentration is not being performed, since the work would only focus on relative concentrations. Thus, to indicate the relative gas concentrations, the sensor's resistance, (R_S) is used in this research. 3D linear regression will be conducted to generate temperature and humidity drift model for each sensor. Given that *(R_S),* ambient temperature and humidity are known, the output model will be able to predict the corrected gas sensor resistance (R_S^*), that minimizes the temperature and humidity effect.

1.6 Thesis Structure

This thesis is divided into 5 chapters covering all expects in research. Throughout the thesis, the activities done during the project is further discussed in the particular chapters. In this report structure, a short summary explaining each the chapters in this thesis is presented.

Chapter 1 describes the project background to reduce the gas sensor to identify problems that occur during measurements. Project aim is described in the research background. Project objectives are guidelines to be undertaken and the scope of the project discussed in Chapter 1. The problem statement and project objectives are summarized.

Chapter 2 discussed the literature review done during the project. In this section, all the related journal, thesis, online reviews are being references in this literature review. This chapter covers the idea of relevant researches on MOX gas sensor with gas sensing technologies used in the previous research and the method of an experiment to optimize the result obtained for the research.

Chapter 3 described the methodology of the whole study step comprising of stages that required to be performed in order to produce the result and conclusion. Gas sensor, PCB design and development, chamber designed, experiment setup, experiment procedure and Linear regression-based machine learning processes were conducted.

Chapter 4 presents and discusses the experimental results. The results obtained are presented in tabulated form as well as plots for easy observation and interpretation. Detailed explanations are discussed based on the observed pattern and link with the theory learned for this research.

Chapter 5 focused on the summary of the project. The overall project done would be concluded in this chapter. This chapter also include discussion of the outcomes obtained from the project and suggests further work.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

This chapter provides literature studies on the work related to this research. The literature review will begin with the discussion on basic gas sensing characteristics and their major differences according to previous researchers. Then a brief overview of current gas sensing technologies will be presented in Section 2.3. The discussion will focus on metal oxide (MOX) sensor and relevant gas sensors technology used in this research. Section 2.4 will explain the sensing operation of the gas sensors. The parameters affecting the sensitivity of MOX gas sensors response will be elaborated in Section 2.5. The K-fold cross validation (CV) technique was used to provide the measure of fit of these candidate models with respect to the data will be discussed in Section 2.6. Then, the relevant methods that will used to correct drift of the gas sensors response will be discussed in Section 2.7.

2.2 Basic Gas Sensing Characteristics

The characteristics of gas sensing has been observed in previous researchers, including sensitivity, response time, recovery time, analyte concentration, operating temperature and detection limit for different material of gas sensors (Kumar et al., 2015). Based on the performance of gas sensor sensing characteristic, an ideal sensor should possess high sensitivity, short response, recovery time and high stability (Dey, 2018).