UNIVERSITI PUTRA MALAYSIA

CAPILLARY-ATTACHED GAS SENSOR SYSTEM DESIGN FOR ELECTRONIC NOSE APPLICATION

BEHZAD BAHRAMINEJAD

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

April 2011

DEDICATION

To My family members especially my beloved wife

and my ever-encouraging parents for their love

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chair: Professor Shah Nor Basri, PhD, F.A.Sc.

Faculty: Institute of Advanced Technology

Since the 1980s, researchers have spent a great deal of effort developing the electronic nose (e-nose) as an artificial olfaction instrument to mimic the mammalian sense of smell. Currently, the e-nose is employed in a wide range of applications, such as food and beverage quality control, environmental monitoring and medical diagnosis. Although published results have indicated great achievement in the field of gas identification systems, fabricating a comprehensive instrument for rapid and real-time gas identification is still difficult and complicated. Most of the efforts to improve electronic nose performance have been in applying diverse gas sensor technologies and signal processing techniques to increase the selectivity of the e-nose. However, the classic structure of the e-nose has remained relatively untouched. Moreover, all the detection parameters are extracted based on the instant trace of the target gas on the sensing element.

In this dissertation, the design and development of a gas identification system based on a developed sensor structure and transient response analysis was studied. An air-

filled capillary was attached to a metal oxide semiconductor gas sensor to fabricate a developed structure and to increase the identifying information of the gas sensor output. The new structure involved a unique gas diffusion coefficient for each target gas as an additional parameter in the transient response of the gas sensor in the reaction of a target gas. A prototype sensor based on the proposed structure was fabricated, and its physical characteristics were investigated. The dimensional effects of new physical attachment, in both length and diameter, were studied, and optimized dimensions were selected. Application of the fabricated prototype gas sensor in detecting five hydrocarbon gases was studied. The results indicated that the sensor successfully distinguished between different applied gases. The ability of the developed structure in a gas mixture analysis was studied, and application of the sensor was assessed to detect components of several mixtures of volatile organic gases. The results indicated that the gas sensor could detect gas mixtures with high accuracy (above 90%). The sensors could separate mixtures including hydrogen from mixtures excluding it. The ability of the optimum sensor structure in real-time gas identification was also investigated. It proved that the early portion of the transient response could be applied to achieve a high accuracy classification performance. Then, the new sensor structure was applied to the design and development of an e-nose. The advantages of the designed e-nose were studied by applying diverse simple and complex odors. The results indicated that the new electronic nose could detect different types of odors with a high classification rate. Therefore, the development of the identifying abilities of the e-nose is another advantage of the new sensor structure. For both the single sensor and e-nose system, different compatible processing and analyzing methods were employed regarding the sensor transient response characteristics. Different pattern recognition and classification methods

were also studied to generate the optimized identification unit.

The new structure also reduced the interfering parameters, a common problem reported in research, and increased the reproducibility of the system. The ability of the developed sensor structure in single and mixed gas identification can be applied to fabricate smarter gas detection instruments and to employ the e-nose in gas chromatography or mass spectrometry as challenging applications for future work.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

REKABENTUK SISTEM PENDERIA GAS DENGAN KAPILARI-TERPASANG UNTUK APLIKASI HIDUNG ELEKTRONIK

Oleh

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Sejak 1980-an, para penyelidik telah menghabiskan banyak usaha mencipta hidung elektronik (e-hidung) sebagai alat penghiduan buatan untuk meniru deria bau mamalia. Pada masa ini, e-hidung digunakan dalam pelbagai aplikasi, seperti pengawalan kualiti makanan dan minuman, pemantauan persekitaran, dan diagnosis perubatan. Walaupun hasil yang diperoleh telah menunjukkan prestasi yang menggalakkan dalam bidang sistem pengecaman gas, namun pembikinan instrumen yang lebih unggul untuk pengecaman gas dengan cepat dan cekap masih sukar dan rumit. Sebahagian besar usaha untuk meningkatkan prestasi hidung elektronik tersebut dilakukan dengan penerapan pelbagai teknologi penderia gas dan teknik pemprosesan isyarat sebagai usaha untuk meningkatkan daya pemilihan e-hidung. Namun, struktur klasik e-hidung tidak begitu banyak disentuh. Tambahan pula, semua parameter pengesanan masih berdasarkan pengesanan segera gas sasaran pada unsur penderiaan.

Dalam disertasi ini, reka bentuk dan pembinaan sistem pengecaman gas dilakukan dengan berdasarkan struktur penderia yang dibina dan analisis terhadap sambutan

fana dikaji. Suatu kapilari yang dipenuhi udara dipasang pada suatu penderia gas semikonduktor oksida logam untuk menghasilkan struktur yang dibina dan untuk menambahkan maklumat pengecaman terhadap keluaran penderia gas. Struktur baharu melibatkan pekali resapan gas yang unik untuk setiap gas sasaran sebagai parameter tambahan bagi sambutan fana daripada penderia gas hasil tindak balas gas sasaran. Suatu penderia prototip berdasarkan struktur yang dicadangkan telah dibikin, dan ciri fizikalnya diselidiki. Kesan dimensi daripada pemasangan fizikal baharu, dari segi panjang dan diameter dikaji, dan dimensi yang optimum dipilih. Prototip penderia gas yang telah terhasil diaplikasikan untuk mengesan lima gas hidrokarbon. Hasil kajian menunjukkan bahawa penderia berjaya melakukan pergesanan perbezaan antara lima gas yang berlainan ini. Kemampuan struktur yang terhasil dalam analisis gas campuran dikaji, dan aplikasi penderia dinilai untuk mengesan beberapa komponen campuran gas organik yang mudah meruap. Keputusan kajian menunjukkan bahawa penderia gas dapat mengesan campuran gas dengan ketepatan yang tinggi (lebih daripada 90%). Penderia dapat memisahkan campuran termasuk hidrogen daripada campuran yang tidak tercakup. Kemampuan struktur penderia optimum dari segi kecekapan mengenal pasti gas turut dikaji. Terbukti bahawa peringkat awal daripada sambutan fana boleh digunakan untuk mencapai pengkelasan kecekapan berketepatan tinggi. Kemudian, struktur penderia baharu diaplikasikan untuk mereka bentuk dan membina e-hidung. Kelebihan e-hidung yang dicipta juga dikaji dengan menggunakan bau yang sederhana dan bau yang rencam. Hasil kajian menunjukkan bahawa e-hidung baharu dapat mengesan pelbagai jenis bau dengan kadar klasifikasi yang tinggi. Justeru, pembinaan keupayaan pengecaman bagi e-hidung merupakan satu lagi kelebihan struktur penderia baharu. Untuk kedua-dua penderia, iaitu penderia tunggal dan sistem e-

hidung, kaedah pemprosesan dan analisis serasi yang berlainan digunakan dengan padanan yang berdasarkan ciri penderia sambutan fana. Kaedah pengecaman dan pengklasifikasian yang berbeza turut dikaji untuk menghasilkan unit pengecaman yang optimum.

Struktur baharu ini juga dapat mengurangkan parameter gangguan, yang merupakan masalah umum dalam kajian, dan meningkatkan daya penghasilan sistem. Keupayaan struktur penderia yang dibina untuk mengenal pasti gas tunggal dan gas campuran boleh digunakan untuk menghasilkan alat pengesanan gas yang lebih bestari dan boleh digunakan oleh e-hidung dalam kromatografi gas, atau spektrometeri jisim sebagai alat yang lebih mencabar bagi menangani pekerjaan yang relevan pada masa hadapan.

ACKNOWLEDGEMENTS

I wish to express my deepest gratitude to the numerous people who have walked with me along the journey of this thesis. First and foremost I would like to express my deep gratefulness to my supervisor Professor Ir. Dr. Shah Nor Basri for his kind assistance, support, critical advice, encouragement, suggestions and direction throughout my research and preparation of this thesis.

I would also like to express my gratitude towards my co-supervisors Dr. Maryam Isa and Associate Professor Dr. Zarida Hambali for their supervision, helpful advice and fruitful discussions that made an invaluable contribution to this dissertation.

My sincere appreciation goes to all the people who have helped and supported me.

Last but not the least, my heart-full gratitude and love to my wife Rana, my mother and my father, my mother-in-law and my father-in-law, and siblings whose unconditional support and love has made this dream comes true to me.

I certify that an Examination Committee has met on **date of viva voce** to conduct the final examination of **Behzad Bahraminejad** on his **Doctor of Philosophy** thesis entitled **"Capillary-attached gas sensor system design for electronic nose application"** in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the Doctor of Philosophy.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted in fulfillment of the requirements for the degree of **Doctor of Philosophy**. Members of the Supervisory Committee were as follows:

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