A HYBRID HUMAN SENSORY MIMICKING APPROACH: AN INTEGRATED E-NOSE AND E-TONGUE SYSTEM

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A Hybrid Human Sensory Mimicking Approach: An Integrated E-Nose and E-Tongue System

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ANN	Artificial Neural Network
BPF	Band Pass Filter
BPNN	Back-Propagation Neural Network
CAD	Computer Aided Designed
CCTV	Closed Circuit Television
CNS	Central Nervous System
CP	Conducting Polymer
CPU	Central Processing Unit
FET	Field Effect Transistor
GC	Gas Chromatography
GC-MS	Gas Chromatography-Mass Spectrometry
HCA	Hierarchical Clustering Analysis
HPF	High Pass Filter
ISE	Ion-Selective Electrode
LPF	Low Pass Filter
MLP	Multilayer Perceptron
MOS	Metal Oxide Semiconductor
MS	Mass Spectrometry
MSG	Monosodium Glutamic Acid
NASA	National Aeronautics and Space Administration
OCM	Odour Capturing Module
PCA	Principal Component Analysis
pH	Potential of Hydrogen
PNS	Peripheral Nervous System
RBFNN	Redial Basis Function Neural Network
RP	Rapid Prototyping
QMB	Quartz Crystal Microbalance
SAW	Surface Acoustic Wave
SOMNN	Self-Organising Map Neural Network
SOP	Standard Operating Procedure
TGS	Taguchi Gas Sensor

ABSTRAK

Pendekatan Sistem Hibrid Penderia Manusia Tiruan : Integrasi Sistem Penderia Bau dan Penderia Rasa

Bau dan rasa adalah dua daripada lima penderia manusia yang sama dengan mamalia yang lain. Kedua-dua penderia ini biasanya digunakan bersama untuk melengkapkan persepsi otak manusia terhadap rasa. Keadaan ini menjadi pemangkin kepada kajian dalam gabungan data daripada beberapa sistem penderia buatan seperti penderia bau dan penderia rasa. Walau bagaimanapun, gabungan data yang dijalankan oleh kajian sebelum ini adalah berasaskan sistem modaliti-tunggal yang berasingan. Berikut dibentangkan pembangunan sistem hibrid yang menggabungkan penderia rasa buatan dan penderia bau buatan di dalam sistem tunggal. Kedua-dua sub-sistem menggunakan komponen-komponen yang sedia ada dan dibangunkan menggunakan teknik *rapid prototyping*. Sistem hibrid ini menggabungkan dua kumpulan penderia yang terdiri daripada penderia gas MOS dan elektrod *ion-selective*. Ia juga terdiri daripada unit pengumpulan isyarat data dan perisian pengcaman yang digunakan menerusi komputer. Sistem ini adalah berdasarkan analisis kualiti yang menyamai sistem penderia manusia dengan menggunakan *Principal Component Analysis (PCA)* dan *Artificial Neural Network (ANN)*. Tiga jenis ujian dijalankan mewakili aplikasi-aplikasi di dalam bidang pertanian, alam sekitar dan pengeluaran makanan. Prestasi sistem modaliti-tunggal telah dibandingkan dengan sistem hibrid ini. Keputusan ujian yang dijalankan menunjukkan sistem hibrid memberikan prestasi yang lebih baik berbanding kedua-dua subsistem tunggal, apabila menggunakan kaedah gabungan data yang bersesuaian, dan mampu mencapai ketepatan sehingga 98.67%. Ini telah membuktikan bahawa sistem modaliti-pelbagai yang lebih mirip kepada sistem penderia manusia memberikan prestasi yang lebih baik berbanding sistem modaliti-tunggal dalam membezakan sampel.

ABSTRACT

A Hybrid Human Sensory Mimicking Approach: An Integrated E-Nose and E-Tongue System

Taste and smell are two of the five human senses that are common among mammalians. These two senses are usually used together to make up the brain's perception of flavour. This has lead to the study of data fusion of multiple artificial sensory systems such as electronic nose and electronic tongue. However, the data fusions performed by these studies are based on separate single-modality systems. Presented is the development of a hybrid system which combines an electronic nose and electronic tongue in a single system. Both sub-system uses off-the-shelf components and developed using rapid prototyping techniques. The hybrid system combines two sensor arrays of MOS gas sensors and ion-selective electrodes. It also consists of a signal-collecting unit and pattern recognition software applied to a computer. The system uses qualitative analysis which is similar to the human sensory system, implementing Principal Component Analysis (PCA) and Artificial Neural Network (ANN). Three tests were performed representing agricultural, environmental and food production applications. The performance of the single-modality systems were compared to the hybrid system. The results show that the hybrid system performed better than the both single sub-systems when appropriate fusion method was used, and able to archive up to 98.67% accuracy. This proved that the multi-modality system performed better in samples discrimination than single-modality system which mimics more closely the human sensory system.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Olfaction (smell) and taste (gustation) are two out of five basic human senses. These two basic senses aid human in daily life. They help to distinguish ripe fruits, bad foods and even used for safety purpose such as the detection of gaseous leakage or burning. Study proved that both senses are related to each other where the human gustatory system cannot perform well if the olfactory system is blocked.

The smell and taste sensation also being used in industrial activity such as in tea and wine classification. However, these human expertise are normally affected by environment and their health and emotion. Therefore, there are many analytical instruments that were designed to replace human expertise.

The analytical instrument such as Gas Chromatography (GC), Mass Spectrometry (MS), Optical Spectrometry and GC-MS are normally used in quantitative analysis. However, there are some disadvantages of using these analytical instruments. The bulky size limits the usage of instrument to laboratory analysis only. These instruments are also expensive and they need an expert in order for these instruments to perform well.

Recently, there are artificial devices that mimic human olfaction and gustation system. They are known as electronic nose (e-nose) and an electronic tongue (e-tongue). These devices more resembling the human olfaction and gustation systems compared to the analytical instruments that have been mention above which normally used in qualitative analysis.

These systems normally consist of an array of sensors with signal handling system, data processing and pattern recognition analysis. The e-nose and e-tongue are being differentiated by their sensors arrays which are gas sensors for e-nose and taste sensors for e-tongue. Both types of sensors work in different type samples. The gas sensors work with the presence of specific gas while the taste sensor work with the presence of specific ion (refer Chapter 2 for further discussion).

It also has been proved that the e-nose and e-tongue can be applied in various applications, from environmental and agricultural industry to medical and other commercial industry (D'Amico, 2000). As human olfaction and gustation sensory system will perform better when both in good condition, thus the combination e-nose and e-tongue which mimic these systems are expected to perform better than the single system.

1.2 Research Objectives

The objectives of this research are:

i) to develop an in-house hybrid artificial sensory system which combines an e-nose and e-tongue.

ii) to define the standard operating procedures (SOP) which will take into account of working priciples for both e-nose and e-tongue and the specific sensors.

iii) to investigate the different data fusion techniques (data fusion levels).

iv) to study and prove whether multi-modality system perform better than single-modality system in samples discrimination and recognition. The hybrid system that combines e-nose and e-tongue is expected to perform better than the single system, which is as similar to the bonding of human olfation and gustation system.

1.3 Research Scopes

The research work consists of five main scopes which are:

i) Development of in-house hybrid system which combines e-nose and e-tongue.

ii) Develope the standard operating procedure (SOP) of the hybrid system.

iii) Comparison of performance of single-modality system (e-nose and e-tongue) with the multi-modality system (hybrid system).

1.4 Thesis Outline

This thesis is organised into seven chapters. The introduction of this research is presented in Chapter 1. It describes the basic preface of the e-nose and e-tongue. This chapter also explains the objectives of this research as well as the thesis outlines.

Chapter 2 presents the literature review of both sub-systems that will be used in this research. It discusses the general fact of human senses, specifically the olfaction (smell) and gustation (taste) and also the e-nose and e-tongue sub-systems. It also describes the data processing, pattern recognition and data fusion technique that will be used to analyse the data obtained from both sub-systems.

Chapter 3 will discuss the initial study of both sub-systems which includes the sensors selection and the basic operating procedure of all sensors used. The evaluation of a single-modal system also will be presented in this chapter. Also, comparison of performace between in-house and commercial e-nose will be discussed in this chapter.

The development of the combined system will be discussed in Chapter 4. It will include the hardware and software development and the system integration and testing which consists of the standard operating procedure of the combined system.

Chapter 5 will discuss the testing and evaluation of the hybrid system. It includes the system and sample preparation, list of samples used and methods of data analysis.

The results and discussion in Chapter 6 will evaluate the performance of the system. Results form e-nose and e-tongue are compared with the hybrid system which comes from two different fusion methods.

Finally, Chapter 7 will conclude the possibility applications of the combined system. It will also describe the problems faced in this research and suggestions for future work.

CHAPTER 2

LITERATURE REVIEW

This chapter discusses the human sensory systems, and also the related research in the area of electronic sensing systems inspired by the former, and the implementation of data fusion. These literatures illustrate the possibilities in the area of the application of bio-mimicking sensing, and how the manipulation of the data from several single sensing or modality systems can improve their performance. These form the basis of the project, and used as the guidance on the development of the system and also to perform analysis.

The human sensory systems are described, followed by the electronic or artificial counterparts, covering the types of systems available, the choice of sensors as well as their applications. The data processing techniques are also discussed. Single systems are described, followed by the implementation of data fusion, and finally the idea of hybrid system.

2.1 Human and Senses

The human nervous system is a complex communication network system. It is composed of a network of cells throughout the body which receives the information about the internal and external environments. After the information is assessed, a signal is then send to an organ that will react with an appropriate response. It is one of major systems that used to regulate the entire processes in the body. Hence, this nervous system can be the most important system in human body.

The nervous system consists of two major parts which are the central nervous system (CNS) and the peripheral nervous system (PNS). The CNS includes the brain and the spinal cord while the PNS made up of all of the nervous tissue outside the CNS, as shown in Figure 2.1.

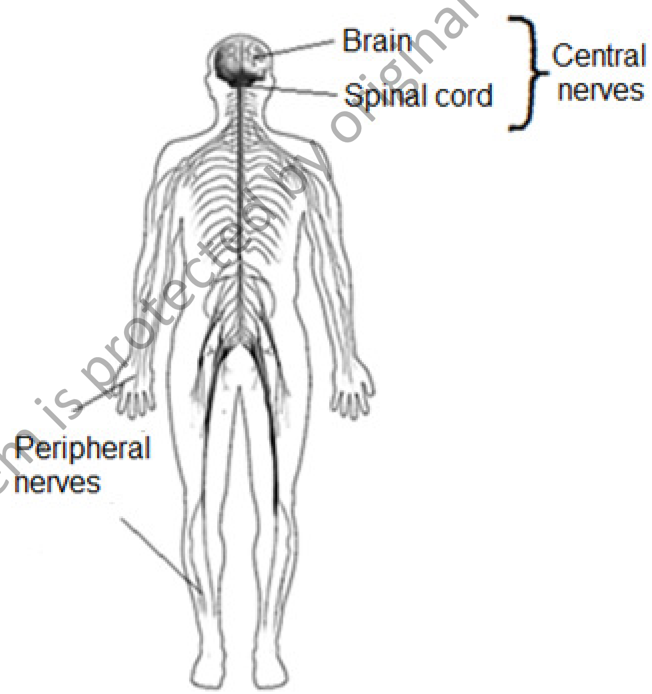

Figure 2.1 Organisation of the nervous system in human body (Standley, 2011).

The brain is an organ, consisting of nervous tissues in the skull. Impulses (signals) from sensory organs and general body control are evaluated in the brain. The spinal cord extends from the brain to the peripheral nerves through the backbone. The nervous tissue consists of bundles of cells that work as circuits for the signals transmissions (Gaudin, 1997).

The PNS, a cable like nerves extend from CNS to throughout the body. It provides pathways for signals travelling to and from the CNS. This system is made up of millions of nerves cells called neurones. There are three types of neurons, namely the afferent neurons, efferent neurons and inter-neurons. The afferent neurons, also known as sensory or receptor neurons carry impulses from receptors or sensory cells on sense organs to the CNS. On the other hand, the efferent neurons carry impulses from the CNS to the effectors such as muscles. The afferent neurons are always linked to efferent neurons indirectly. In most cases, the efferent neurons reflexion is a reaction to afferent neurons senses. Figure 2.2 shows the connection of both neurons.

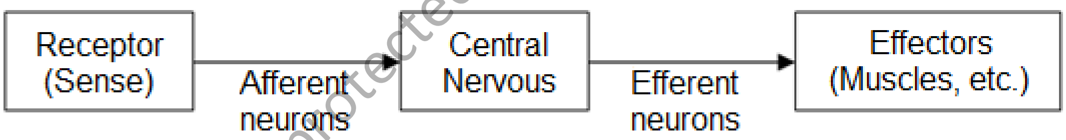

Figure 2.2 The connection between afferent neurons and efferent neurons

2.2 Human Sensory Sub-Systems

The human sensory system is a part of human nervous system that responsible for processing sensory information. It consists of sensory receptors that receive stimuli (information) from internal and external environment, neural pathways that conduct the information to brain and parts of brain that involves in sensory perception and process the information. The information is called sensory information and it may lead human to conscious awareness. The interaction of human with the surrounding environment is carried out through sensory systems that respond to a variety of stimuli such as light, sound, pressure and chemicals.

The human sensory system is an amalgamation of sub-sensing systems, such as

i) visionary (sight),

ii) auditory (hearing),

iii) somatosensory (touch),

iv) olfaction (smell) and

v) gustation (taste).

All humans respond to chemical information through a process known as chemoreception. The chemical signals play a major role in feeding, territorial recognition, sexual behaviour and detection of potential harmful conditions such as fire, gas and bad food. Two types of chemoreception have been distinguished which are specialised into smell and taste. These senses normally show the quality of discrimination but sometimes can express the quantitative information.

2.2.1 Olfaction System

The olfaction system represents one of the oldest sensory modalities in the history of mammals (Vokshoor & McGregor, 2010). As a chemical sensor, the olfaction system detects food and influences social and sexual behaviour. It involves the detection and perception of chemical floating in the air called odour.

A simple odour is usually a small, polar molecule that will enter the nasal cavity and then sensed by the human olfaction system. Odour sensations are caused by the interaction of odorant with specialised receptors in the olfaction epithelium in the top of nasal cavity. The signals that are caused by the interaction of odorant with olfaction receptors in the olfaction epithelium are transmitted to the olfaction bulb and finally to the brain.

Odour sensations are usually characterised by the group of description, such as sulphurous, fruity, floral and earthy or by their specific sources such as strawberry or orange. The range of distinguishing odour sensations is wide. A skilled perfume chemist can recognise and distinguish up to 8,000 to 10,000 different substances.

The sense of smell is a sensitive system that can respond to very low concentrations of chemicals. However, it is estimated that only 2% of the volatile compounds available in a single sniff will reach the olfaction receptors and as few as 40 molecules the odorant are sufficient to perceive an odour. In a day, odorants have huge opportunities to reach olfaction receptors during the inhalation and exhalation process. An average person breathes 15 times per minutes which an average of 0.5 litres of air per breath.

Generally, humans are prone to fatigue, and have the tendency to be inconsistent. In certain situation, like winter, cold or rainy environment, this ability is sometimes blocked which a person cannot smell correctly.

Also, there are some elements or volatile compounds that are “invisible” to the human olfaction. This is because these compounds are odourless and colourless, and hence cannot be detected by the human olfaction sub-system. Three most common gases; hydrogen, oxygen and nitrogen are colourless and odourless. Table 2.1 shows some of the elements and common compounds with their properties (Stoker, 2005).