An Efficient Electronic Nose System for Odour Analysis and Assessment

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Declaration

I hereby declare that except where specific reference is made to the work of others, the contents of this dissertation are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other university. This dissertation is my own work and contains nothing which is the outcome of work done in collaboration with others, except as specified in the text and Acknowledgements.

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Abstract

An electronic nose (e-nose) is capable of identifying chemical compounds through sensing and analysing odour molecules. As a type of machine olfaction, e-nose plays a significant role in the odour analysis area and has received considerable attention from researchers all over the world. The e-nose system comprises a set of active gas sensors that detect the odour and transduce the chemical vapours into electrical signals. The odour "fingerprint" captured by the gas sensors can then be analysed and identified with pattern analysis methods, e.g., Principal Component Analysis (PCA), Cluster Analysis (CA), Support Vector Machine (SVM), and Artificial Neural Networks (ANNs). E-nose has been extensively applied in the areas of agriculture, medical diagnosis, environmental monitoring and protection, food safety, the military, cosmetics and pharmaceuticals.

In order to meet the growing demand from the global odour analysis market, a novel e-nose system, which has a high-efficiency and low-cost odour analysis, was designed and built in this dissertation through collaboration with different research areas. Firstly, inspired by the knowledge of the human olfactory system, an automated fault monitoring and alarming electronic nose (e-nose) system, named “NOS.E”, for odour detection and identification has been designed. This design is based on reliable hardware and software designs as well as an airflow intake system design which is the most significant part of NOS.E. Just as the air inhalations are important and necessary activities for the olfactory perception by controlling the airflow in the human olfactory system, the airflow control design is a crucial and essential element to guarantee the precise odour analysis procedure in the e-nose system. Different parts of the NOS.E are built together under a particular control logic, which was designed to improve the e-nose test efficiency by saving operation time. In addition, the fault detection and

alarming design generates a high-reliability performance for the e-nose by constantly monitoring the working status of the air intake system, to make sure all the actuators are working under the guidance of the proposed control logic.

A novel e-nose data pre-processing method, based on a recently developed non-parametric kernel-based modelling (KBM) approach is presented. The experimental results show that when extracting the derivative-related features from signals collected by the NOS.E, the proposed non-parametric KBM odour data pre-processing method achieves more reliable and stable pre-processing results compared with other pre-processing methods such as wavelet package correlation filter (WPCF), mean filter (MF), polynomial curve fitting (PCF) and locally weighted regression (LWR). Moreover, this dissertation also proposes a novel e-nose pattern analysis algorithm, which is a hybrid of genetic algorithm (GA) and supervised fuzzy support vector machine (FSVM). GA was used to select the informative features and the optimal model parameters of FSVM. FSVM was used as a fitness evaluation criterion and the sequent odour classifier, which would reduce the outlier effects to provide a robust classifier which has a steady classification accuracy.

In addition, several studies were conducted with the NOS.E system. The first was to evaluate the performance of NOS.E based on data collected from different types of alcohols. A comprehensive two-dimensional gas chromatography coupled with time-of-flight mass spectrometry (GC×GC-TOFMS) was used to provide the standard comparison for the evaluation in this study. The second study focused on the effectiveness of KBM data pre-processing method and FSVM odour pattern analysis method. The third study explores the potential to implement NOS.E in the biomedical engineering area, while the fourth study applied NOS.E in the wildlife protection area by rapidly identifying legal from illegal wildlife parts. As a proof-of-concept test, water buffalo horn and rhinoceros horn samples were selected as the test targets in this study.

The study results indicated the reliability and effectiveness of the developed NOS.E system. The NOS.E system is able to be applied to various applications based on the user-friendly and rapid odour analysis tests. Moreover, the NOS.E has the potential to be a universal odour analysis platform implemented in different applications.

Publications

The contents of this thesis are based on the following papers that have been published, accepted, or submitted to peer-reviewed journals and conferences.

Journal Papers:

1. Zhang, Wentian, Taoping Liu, Lin Ye, Maiken Ueland, Shari L. Forbes, and Steven W. Su. "A novel data pre-processing method for odour detection and identification system." Sensors and Actuators A: Physical, 287, 113-120, 2019.

2. Zhang, Wentian, Taoping Liu, Maiken Ueland, Shari L. Forbes, Rosalind X. Wang, and Steven W. Su. "Design of an efficient electronic nose system for odour analysis and assessment." Measurement (Under review).

3. Zhang, Wentian, Taoping Liu, Steven W. Su, Shari L. Forbes, and Maiken Ueland. "Development of the Electronic Nose for Wildlife Products Identification." Forensic science international (Submitted for publication).

4. Liu, Taoping, Wentian Zhang, Peter McLean, Maiken Ueland, Shari L. Forbes, and Steven W. Su. "Electronic Nose-Based Odor Classification using Genetic Algorithms and Fuzzy Support Vector Machines." International Journal of Fuzzy Systems 20, no. 4: 1309-1320, 2018.

5. Liu, Taoping, Wentian Zhang, Lin Ye, Maiken Ueland, Shari L. Forbes, and Steven W. Su. "A novel multi-odour identification by electronic nose using non-parametric modelling-based feature extraction and time-series classification." Sensors and Actuators B: Chemical, 298, 126690,2019.

Conference Papers:

1. Zhang, Wentian, Taoping Liu, Miao Zhang, Yi Zhang, Huiqi Li, Maiken Ueland, Shari L. Forbes, X. Rosalind Wang, and Steven W. Su. "NOS. E: A New Fast Response Electronic Nose Health Monitoring System." In 2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), pp. 4977-4980. IEEE, 2018.

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