The sense of smell is one of the essential senses of human being. Human experts have been used for years for accessing quality of food and drink, perfumes, cosmetics and chemical products. But human olfactory sensing is not consistent as it may get affected by mental and physical health and fatigue. Thus to identify a particular aroma quantitatively and express the characteristics of volatile components of gases, it is necessary to develop an instrument that can analyse the exact quality and quantity of a particular odour [1]-[5]. In recent times, intelligent odour sensing systems are receiving more attention both in industries and research activities. The concept of the artificial olfaction had its beginnings with the invention of the first gas multisensory array in 1982 [2], while the design idea of artificial odour detection system comes from the capability of the mammalian olfactory organ [6].

With the progress in the sensor technology, electronic devices as well in different computational algorithms, the different basic units of the mammalian olfactory organ can be designed artificially. An artificial odour detection system has widespread and common applications in many areas like industrial production, in automotive industry for detection of polluting gases from vehicles, medical applications where electronic noses can early detect diseases, for indoor air quality supervision like detection of carbon monoxide and in environmental studies like greenhouse gas monitoring [7-9]. Researchers have worked on various aspects to enhance the performance of the odour sensing system in terms of its sensitivity, selectivity, response time, energy consumption, reversibility and fabrication cost [5]. An artificial odour detection system, popularly known as Electronic nose (E-nose) consists of a multisensor array for gas detection, an information-processing unit such as an artificial neural network (ANN), software with digital pattern recognition algorithms, and reference databases for
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Identification and classification of odours [7-11]. Research in different aspects of the Electronic Nose has been reported by various researchers.

Metal oxide semiconductor (MOS) gas sensors are commonly used in odour detection systems [12]. Researchers have operated MOS gas sensors in static operation mode and dynamic operation mode to extract relevant features. Under static mode of operation, the output signal becomes stable and easily measurable, but provides less discriminatory information about the tested gas. On the other hand the dynamic response of the gas sensors are found to produce a huge set of features that helps for better classification. Dynamic operation mode has been investigated by various researchers with diverse shapes of the heating waveform [13]. In the past few years modulating the working temperature of the sensors using various heating waveforms has been considered as the most used dynamic mode to enhance the selectivity of the sensors [14]-[15]. In [16], Nakata et al. used a sinusoidal heating waveform for MOS gas sensor and extracted characteristic features using fast Fourier transform (FFT). The FFT features were used for gas discrimination. In [17], Ngo et al. interrogated an array of six MOS gas sensors with a triangular waveform of frequency 25mHz to identify environmental and industrial gases. In [18], Bukowiecki et al. interrogated an array of four MOS gas sensors with various heating waveforms like sawtooth, triangular etc. in the design of a gas alarm system. They concluded that a gas could be identified from the resulting characteristic waveform of temperature modulation.

The investigation of various heating waveform has been reported by Huang et al. in [19]. They interrogated MOS gas sensors with various heating waveforms such as rectangular, pulse, sawtooth, triangular, sinusoidal etc. and used five chemicals as odour source. They concluded that more discriminatory features are obtained when the sensors are modulated with a low frequency and a small number of sensors are sufficient for gas discrimination. In [20], Osuna et
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al. modulated the temperature of MOS gas sensors with sinusoidal waveforms of various frequencies to enhance the selectivity of sensors. They concluded that low frequency modulating waveform provides more characteristic waveform of the target gas. Although the use of various heating waveform have been reported by various researchers, literatures on the determination of best waveform for temperature modulation in a particular application is not available. Different modulation waveform varies the sensor temperature and corresponding reaction kinetics in its own way resulting in different characteristic response waveforms. Therefore the optimum modulating waveform may be found out which will result in the production of the best and informative signals for a particular odour data set and enhance the classification performance of the pattern recognition (PARC) engine.

Sensor optimization is another area which often leads to enhance the performance of E-nose. Hence for a particular application, the subset of sensors has to be optimized for enhanced classification performance and reduced system complexity. Sensor optimization in E-nose has been reported by various researchers. In [21], Pardo et al. optimized their sensor of E-Nose system which consisted of 20 sensors. They have used the exhaustive search approach to determine the best 5 sensor configuration suitable for their task. The objective function used was the classification performance of a classifier based on MLP and LDA. In [22], Phaisangittisagul et al. optimized sensor subset using a genetic algorithm based approach. The objective function used was the classification performance of a \textit{k-nearest neighbour} (k-NN) based classifier. They have performed various experiments with different datasets. In the dataset of coffee, they presented results where their algorithm was able to optimize a sensor subset of 4 sensors from a set of 15 sensors.

Dynamic operation of MOS gas sensors results in huge amount of features leading to increase in the dimension of the feature vector. Those redundant and
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less important features need to be eliminated or else it will lead to increased complexity of PARC and degrade the classification performance. Feature selection has been reported by various researchers [23-25]. In [26], Boilot et al. reported a feature selection method based on genetic algorithm. They were able to obtain a reduced feature subset containing 20 to 30 features from a total of 72 features in their E-nose system. The optimized feature subset enhanced the classification accuracy to 94.3% from 75.2% with the original dataset. In [27], Lin et al. reported a feature selection algorithm by combining support vector machine (SVM) and particle swarm optimization (PSO). In the algorithm the classification accuracy of a SVM based classifier was used as the objective function. An enhanced classification accuracy of 81.62% to 100% was obtained among different datasets using the algorithm.

Researchers have reported various portable odour detection systems. Some of the desirable properties of portable odour detection systems are small, lightweight and low cost. The main difficulty in size reduction of the product is that it needs to have a high powered processing unit to perform odour signal manipulation and classification using complex algorithms. However to perform simple tasks using simple algorithm, a microprocessor or microcontroller unit can be used to design a portable odour detection system as reported in [28]-[31]. In [28], Tang et al. developed a prototype of a portable E-nose consisting of eight sensors, a data acquisition interface and a microprocessor, to identify the fragrance of three fruits. In [29], the design and development of a wireless and portable E-nose has been reported which was used to monitor the volatile organic compounds of musts of different grapes varieties and different grades of ripeness for several harvests. In [30], an E-nose system having six tin oxide based Taguchi gas sensors, a microcontroller based real time data acquisition unit and a portable computer has been reported and used to investigate the fish freshness in real time. The processing was done using Principal component analysis (PCA) and support vector machines (SVMs) to evaluate the result. In [31], another prototype of a
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fast, flexible and portable and a low cost electronic nose based on an ARM microcontroller development boards has been reported. The prototype consisted of a sensor chamber with four tin oxide (Figaro) gas sensors with two small pumps, two electromechanical valves and a display unit. The system was used to measure the ethanol content of wine using neural network based classifier.

On the basis of the literature review the present research work towards the development of a portable and embedded system for real time identification of odour is carried out with the following objectives.

1) Development of a prototype portable system for real time data acquisition and odour detection of different odours.
2) Optimization of sensors in the portable E-nose system based on exhaustive search method combined with Euclidean inter-intra class distance ratio.
3) Evaluation of best waveform for temperature modulation in the portable E-nose for generation of most informative features.
4) Optimization of features for performance enhancement and complexity reduction of the portable odour detection system by suitable feature selection method.

With the above quoted objectives, the research work is carried out as stated below—

1) An odour detection system with nine MOS gas sensors was designed and developed to carry out further research. The system consisted of a microcontroller based heating waveform generation and driving circuit to modulate the temperature of MOS gas sensors. A real time microcontroller based data acquisition system was developed along with LabView based software for computer based data acquisition.

2) The optimized subset of sensors of four sensors from among the array of nine sensors of the E-nose system designed for 16 different target gases has been found. The optimization was performed by exhaustive search method
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[32] using Euclidean inter-intra class distance ratio as the objective functions. All the 511 possible combinations of nine sensors were considered and the Euclidean inter-intra class distance ratio was calculated. Based on the distance ratio the optimized subset of gas sensors has been established.

3) The best waveform for temperature modulation of MOS gas sensors in the portable E-nose system for detection of 16 different gases was evaluated. A total of nine different modulating waveforms were considered and the best waveform which resulted in best class separation of the target gases was determined using Euclidean inter-intra class distance ratio as a class separation measure.

4) The optimized subset of 14 features from among 40 features of four optimized sensors has been found. Two different feature selection algorithm were considered – sequential forward search and particle swarm optimization using Euclidean inter-intra class distance ratio as the objective function [33]-[34]. The particle swarm optimization resulted in better subset of features than the sequential forward search algorithm. Based on the optimized feature set, an artificial neural network based odour classification algorithm was trained in Matlab software. The weights obtained from training were used to implement the artificial neural network recall phase on the microcontroller for embedded gas detection system.

Thesis outline

Chapter 1 gives an introduction to various gas sensors, odour detection systems, sensor and feature optimization method, pattern recognition techniques and review of literature as the basis of objectives achieved in this research.

Chapter 2 describes the experimental setup for odour data acquisition developed to carry out the research. The detail description of different components and circuits of the system is described in the chapter.
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Chapter 3 presents a literature review on the different methods for sensor optimization. A method to optimize the sensor array in the portable E-nose system is described and results presented.

Chapter 4 presents a literature review on the different temperature modulating waveforms that are used for enhancing the features in MOS gas sensor array. A method to determine the best waveform for temperature modulation is discussed and results are presented here.

Chapter 5 presents a review of literature on different methods for feature selection. The chapter discusses and presents the results of various feature selection methods investigated during the research. The detail design step of PARC for the embedded odour detection system is discussed in this chapter.

Chapter 6 summarizes the thesis and presents the future scope of this research work.

References


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