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Research Article

Artificial olfactory system with fault-tolerant sensor array

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ABSTRACT

Numerous applications of artificial olfaction resulting from research in many branches of sciences have caused considerable interest in the enhancement of these systems. In this paper, we offer an architecture which is suitable for critical applications, such as medical diagnosis, where reliability and precision are deemed important. The proposed architecture is able to tolerate failures in the sensors of the array.

In this study, the discriminating ability of the proposed architecture in detecting complex odors, as well as the performance of the proposed architecture in encountering sensor failure, were investigated and compared with the generic architecture. The results demonstrated that by applying the proposed architecture in the artificial olfactory system, the performance of system in the healthy mode was identical to the classic structure. However, in the faulty situation, the proposed architecture implied high identification ability of odor samples, while the generic architecture showed very poor performance in the same situation. Based on the results, it was possible to achieve high odor identification through the developed artificial olfactory system using the proposed architecture.

1. Introduction

Various investigations have been reported regarding the enhancement of the Artificial Olfactory System (AOS). In 1994, Gardner and Bartlett offered the following definition for the electronic nose [1]: “An electronic nose is an instrument, which comprises an array of electronic chemical sensors with partial specificity and an appropriate pattern-recognition system, capable of recognizing simple or complex odors.”

Based on the above definition, an AOS is comprised of two main partitions: an array of gas sensors, and a pattern recognition unit. The sensor array acts like olfactory receptors in biological olfactory system. To achieve high classification and recognition rates, the sensor array is generally composed of several sensors with different selectivity patterns which are chosen based on the sensitivity to a particular gas intended for detection [2]. An essential concept in designing a sensor array is the different sensitivity profile of each sensor over the range of odors expected as the target application. Therefore, the sensor array for different odors generates unique response patterns similar to fingerprints. The outputs of the sensor array are utilized for signal processing and odor classification units. For gas identification, diverse methods and techniques could be applied at these phases. Sensor technology and signal processing categories are the subject of the majority of reports concerning the development of artificial olfaction [1,3,4].

Nowadays, artificial olfactory systems are used in broad fields such as food [5,6], beverage[7,8], environment [9,10], medicine [11], etc. Most researchers have focused on the gas sensors of the system, and the development of signal processing and pattern recognition techniques. At the same time, various attempts have investigated the gas sensors by applying the different types of sensors, such as conductive polymers [12–14], metal-oxide [15–17], surface acoustic wave [18–20], quartz crystal microbalance [21,22], and developing the structure of the sensor [23–26]. In terms of improving signal processing, various efforts have been reported on signal processing, feature extraction and classification techniques [4,27,28].

On the other hand, for critical applications, such as medical diagnosis, reliability and precision are important. A study on the aging of gas sensors demonstrated that, due to gas exposure, after ten months, the fractional change in resistance had decreased due to the aging issue, which limits the operational life of the sensor [29]. Furthermore, devices for medical applications must have a high level of reliability. Faults in medical equipment have been very costly in terms of deaths and injuries [30]. A report from the US Food and Drug Administration (FDA) documented that about 44% of the quality-related problems were the result of errors that could have been prevented through effective design controls [31].

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A study reported that of the 15,000 products used in hospitals, about 4% to 6% were sufficiently dangerous to warrant immediate correction [32].

As mentioned earlier, individual sensors are prone to high rates of failure [29]. Therefore, there is a critical need for an architecture that can cope with the failure of the sensors and also provide acceptable quality of data for artificial olfactory systems.

The purpose of this paper is to offer a fault-tolerant architecture for the sensor array of an artificial olfactory system which can resist failures in the sensors of the array. The result is a system that can suffer from failure but it does not affect its performance, and the system is able to recover from the failure without direct human intervention. In the proposed architecture, any fault arising is masked and erroneous data are eliminated from the results.

2. Framework of the proposed architecture

The structure includes a sensor array, signal pre-processing unit, knowledge based pattern recognition and classification unit, as well as reference-library databases [1,33–35]. The generic architecture of the artificial olfactory system is shown in Fig. 1. The major module in artificial olfaction is the sensor array [33].

In sensor selection we should consider a number of criteria such as, high sensitivity to the target samples proposed for detection. Moreover, to guarantee wide range detection capabilities, sensors should have low selectivity in the direction of being sensitive to different chemical compounds. Also, sensors should have fast recovery time, low calibration requirements and, short recording time [33,36].

The proposed framework model is illustrated in Fig. 2. In the proposed architecture, the sensor array consists of several clusters. The clusters of sensors are used to indicate the target gases. Each cluster is an array of a unique type sensor that is chosen based on the target gas. The plurality of output signals from each of the clusters is transferred to a virtual sensing system which is called 'virtual sensor'. The virtual sensors use information available from the physical sensors in the cluster to compute an estimate of a median data. Therefore, the median data from the plurality of output signals from each of the clusters is extracted by applying statistic median method in the virtual sensing system.

Fig. 3 presents the data flow for the proposed architecture. Odor molecules ($X_{i,j}$) cause a response in each individual sensor j within the cluster i, and the sensor generates a time-dependent electrical signal ($\overline{X_{i,j}}$).

The sensor signal relates to several parameters including the nature of the odor, the speed of transference of the odor from the source to the sensor, the reaction of the aroma molecules with the sensing layer, and the environmental parameters including temperature and humidity [1].

In the virtual sensor, the estimated value (y_i) from the cluster is extracted. The responses generated by the virtual sensor array are used to compose a dataset ($[\boldsymbol{Y_{mn}}]$), which is fed into a signal pre-processing unit. Signal pre-processing is done to prepare the data for pattern analysis and modify the median data from all of the clusters to minimize the effect of environmental disturbances [37].

The next stage is dimensionality reduction. Feature reduction provides a faster model, enhances pattern recognition performance and prediction efficiency, and enables ease of modeling and interpretation [38,39]. In this stage, principal component analysis (PCA) is applied on preprocessed data.

Multivariate pattern analysis is the next stage after feature reduction and extraction. The aim of pattern recognition is the attribution of label prediction for an unknown odor.

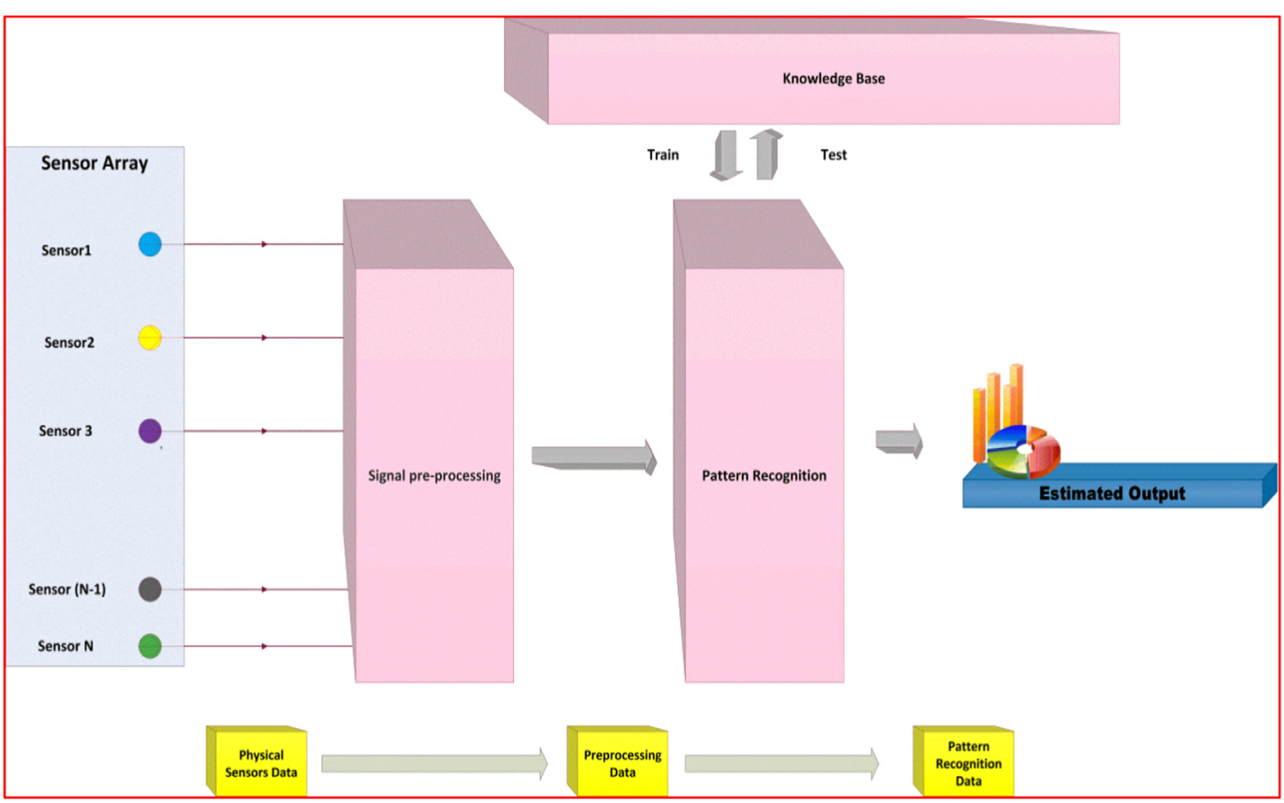

Fig. 1. Generic architecture of artificial olfactory system.