Electronic Nose for a Fire Detection System by Neural Networks ⋆

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Abstract: Conventional fire detectors use the smoke density or the high air temperature to trigger the fire alarm. These devices lack of ability to detect the source of fire in the early stage and they always create false alarms. In this paper, a reliable electronic nose system designed from the combination of various metal oxide gas sensors is applied to detect the early stage of fire from various sources. The time series signals of the same source of fire in every repetition data are highly correlated and each source of fire has a unique pattern of time series data. Therefore, the error back propagation method can classify the tested smell with 99.6% of correct classification by using only a single training data from each source of fire. The use of k-means algorithms results in 98.3% of correct classification which also shows the high ability of the electronic nose to detect the early stage of fire from various sources accurately.

Keywords: Electronic nose, pattern recoginiton, neural networks, error back-propagetion, fire detection

1. INTRODUCTION

Over the last decade, odor-sensing systems (so-called electronic nose systems) have undergone important developments from technical and commercial viewpoints. The electronic nose (EN) refers to a device of reproducing human sense of smell based on sensor arrays of smell and pattern recognition methods. Recently, there are several commercial EN instruments currently in use in the world such as quality control of food industry (Baric et al. [2006], Charumporn et al. [2003]), environmental protection (Kusuke et al. [1995]), public safety (Norman et al. [2003]) and space applications (Young et al. [2003]).

In this paper, we will explain the human olfactory process and the EN system. After surveying various types of the odor sensors, we explain the odor sensors and then the reliability of a new EN system developed from various semiconductor metal oxide gas sensors (MOGSs) is presented to specify the smell from various sources of fire.

James A. Milke [1995] has proved that two kinds of MOGS have the ability to classify several sources of fire more precisely compared with conventional smoke detector. However, his results achieve only 85% of correct classification.

In this paper, a new EN (Charumporn et al. [2003]) is applied to measure smells from various sources of fire such as household burning materials, cooking smells, the leakage from the liquid petroleum gas (LPG). The new EN has been successfully applied to the classification of not only similar smells from different kinds, but also the same kind of smell at different concentration levels. The time series signals of the MOGS from the beginning to the time until the MOGS fully adsorbs the smell from each source of fire are recorded and analyzed by the error back-propagation (BP) neural network and the k-means algorithm. The average classification rate of 99.6% can be achieved by the BP method with only a single training data set from each source of fire. The accuracy with k-means algorithm is 98.3%, which is much better than the results in Milke [1995]. These results confirm the reliability of this new device in detecting various sources of fire in the early stage.

2. HUMAN OLFACTORY PROCESSES

Although the human olfactory system is not fully understood by physician, the main components about the anatomy of human olfactory system are the olfactory epithelium, the olfactory bulb, the olfactory cortex, and the higher brain or cerebral cortex.

The first process of human olfactory system is to breathe or to sniff the smell into the nose. The difference between the normal breath and the sniffing is the quantity of odorous molecules that flows into the upper part of the nose. In case of sniffing, most air is flown through the nose to the lung and about 20% of air is flown to the upper part of the nose and detected by the olfactory receptors.

In case of sniffing, the most air is flown directly to the upper part of the nose and interacts with the olfactory receptors. The odorous molecules are dissolved at the mucous layer before interacting with olfactory receptors in the olfactory epithelium. The concentration of odorous molecules must be over the recognition threshold. After

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that, the chemical reaction in each olfactory receptor produces an electrical stimulus. The electrical signals from all olfactory receptors are transported to olfactory bulb. The input data from olfactory receptors are transformed to be the olfactory information to the olfactory cortex. Then the olfactory cortex distributes the information to other parts to the brain and human can recognize odors precisely. The other parts of the brain that link to the olfactory cortex will control the reaction of the other organ against the reaction of that smell. When human detects bad smells, human will suddenly expel those smells from the nose and try to avoid breathing them directly without any protection. This is a part of the reaction from the higher brain. The next process is to clean the nose by breathing fresh air to dilute the odorous molecules until those concentrations are lower than the detecting threshold. The time to dilute the smell depends on the persistence qualification of the tested smell.

The processes to analyze smell by a human nose can be summarized by a diagram shown in Fig. 1.

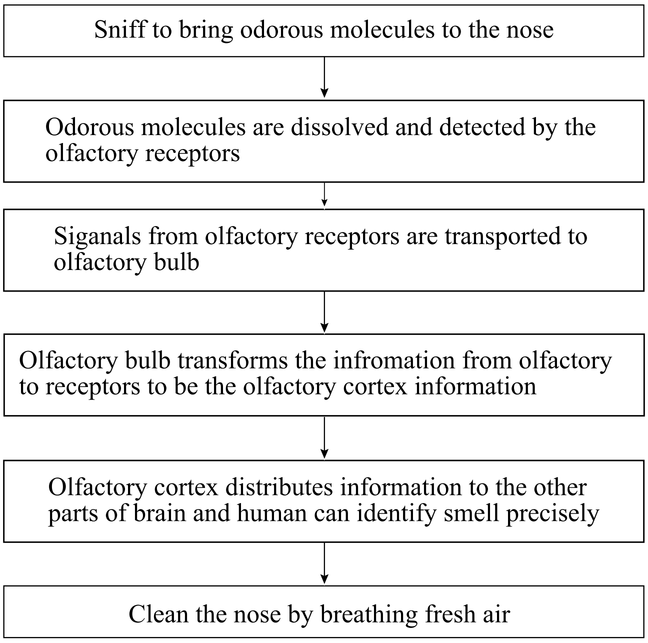

Fig. 1. Olfactory system

2.1 Metal Oxide Gas Sensors as Olfactory Receptors

A commercial MOGS has been developed widely for more than thirty years. Generally, it is designed to detect some specific smell in electrical appliances such as an air purifier, a breath alcohol checker, and so on. Each type of MOGS has its own characteristics to response to different gases. When combining many MOGSs together, the ability to detect the smell is increased. An EN system shown in Fig. 1 has been developed based on the concept of human olfactory system by using the combination of MOGSs from FIS Inc. listed in Table 1 as the olfactory receptors in the human nose. The MOGSs unit is combined with the air flow system to flow the air and the tested smell into the MOGSs unit. The data logger converts the analog signals to digital signals and stores them in the data recording system before being analyzed by multivariate analytical methods, such as the BP method and the k-means algorithms. The main part of the MOGS is the metal oxide element on the surface of the sensor. When this element is heated at a certain high temperature, the oxygen is absorbed on the crystal surface with the negative charge. The reaction between the negative charge of the metal oxide surface and deoxidizing gas makes the resistance of the sensor vary as the partial pressure of oxygen changes. Based on this characteristic, we can measure the total voltage changes during the sensors absorbing the tested odor.

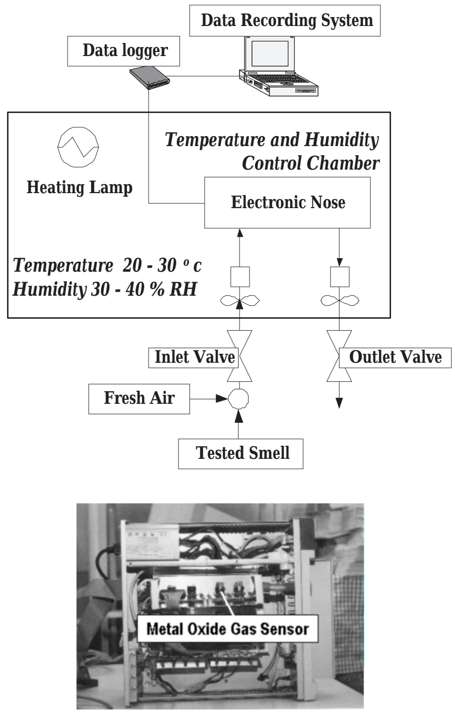

Fig. 2. (above) Schematic diagram of the electronic nose system (below) Inside of the EN containing various metal oxide gas sensors

Table 1. List of MOGSs from the FIS Inc. Used in This Experiment

Sensor Model	Main Detecting Gas
SP-53	Ammonia, Ethanol
SP-MW0	Alcohol, Hydrogen
SP-32	Alcohol
SP-42A	Freon
SP-31	Hydrocarbon
SP-19	Hydrogen
SP-11	Methane, Hydrocarbon
SP-MW1	Cooking vapor

Since the MOGS is sensitive to the temperature and the humidity, the MOGSs unit is put in a small chamber that has a heating system to increase the air temperature during winter season. The heating unit can also decrease the air humidity in the chamber. The clean water is manually sprayed into the chamber when the humidity drops lower than the control level. In this experiment the temperature in the chamber is kept between 20-30 °C and the humidity is kept between 30-40%RH. The tested smell is sucked to mix with the fresh air before passing to the