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Research and Cutting-Edge Application of Electronic Nose

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ABSTRACT

The electronic nose is composed of an array of sensors and various recognition methods, which can recognize and classify different odors, and is inspired by the olfactory organs of animals. With the development of the technology, the electronic nose is applied more extensive. At the beginning, the electronic nose is used to identify the smell of foods, but now it is able to make important contributions in more occasions, such as chemical plants, public toilets, environmental quality monitoring, explosives detection and so on. Electronic nose can be smelled gas into electrical signals by through the sensor array, diverse sensors will respond differently to a different gas, so the gas can be identified. Therefore, when designing the electronic nose, it is particularly important to choose the type of sensors, and the size and arrangement of the array are considered to identify more gases. Nowadays, how to make the electronic nose smaller, detect more accurately, and how to use it better (such as portable) is one of the directions of electronic nose research.

1. Introduction

The electronic nose was first developed for the rapid detection of food, which is composed of gas sampling, sensor array and signal processing system, can realize the identification of the measured gas and continuous monitoring within a certain period of time. Electronic nose detection not only greatly improves the detection speed of the gas to be measured, but also increases the detection accuracy, so the human error can be avoided. Besides, the electronic nose even can be applied in places where people and animals cannot reach, such as narrow tunnels, places with high toxic gas concentrations, etc., which effectively reducing manpower and material resources, so the electronic nose is playing an increasingly important role in various fields. Nowadays, the study of electronic nose has become more and more extensive.

The electronic nose is a new type of measurement tool, similar to the olfactory system of living organisms, and capable of gas recognition. Usually, the electronic nose is composed of many gas sensors, information processing systems and identification methods. In recent years, the electronic nose has become a hot spot in the industry research, how to accurately identify and classify the nose, how to make the electronic nose smaller under the premise of ensuring the function, etc., are the current research directions. In addition, not only to make the electronic nose an integral part of the robot, people are also committed to the study of handheld electronic nose, which is also convenient to carry when solving problems.

2. Electronic nose sampling

Sampling is a very critical step in the electronic nose system, which generally classified into static sampling and dynamic sampling, and dynamic sampling is commonly carried out in the electronic nose. Because more useful information can be obtained by dynamic sampling, there are more dynamic sampling researches. Classical dynamic sampling is divided into three processes: rise, steady state, and recovery. However, the classical dynamic sampling method takes a lot of time to recover from sampling and is inefficient, so some new sampling methods that can improve efficiency are needed.

Inspired by biological respiration, Meng et al.[2] proposed a bionic breath sampling method, people's breathing is divided into long-term deep breathing and short-term shallow breathing, deep breathing inhale exhalation time is longer and similar to the classic dynamic sampling. The idea of bionic breath sampling is similar to shallow breathing, inspiratory exhalation time is shorter, and the cycle is more frequent. Bionic breath sampling is divided into three circulating subsections, each of which consists of four stages, namely inhalation, cessation, exhalation, and cessation. Due to frequent sampling, the original response data of the sub-loop can be

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directly used for feature extraction, without the need for classical dynamic sampling which not only to extract its original response data but also to differentiate it to obtain sufficient features.

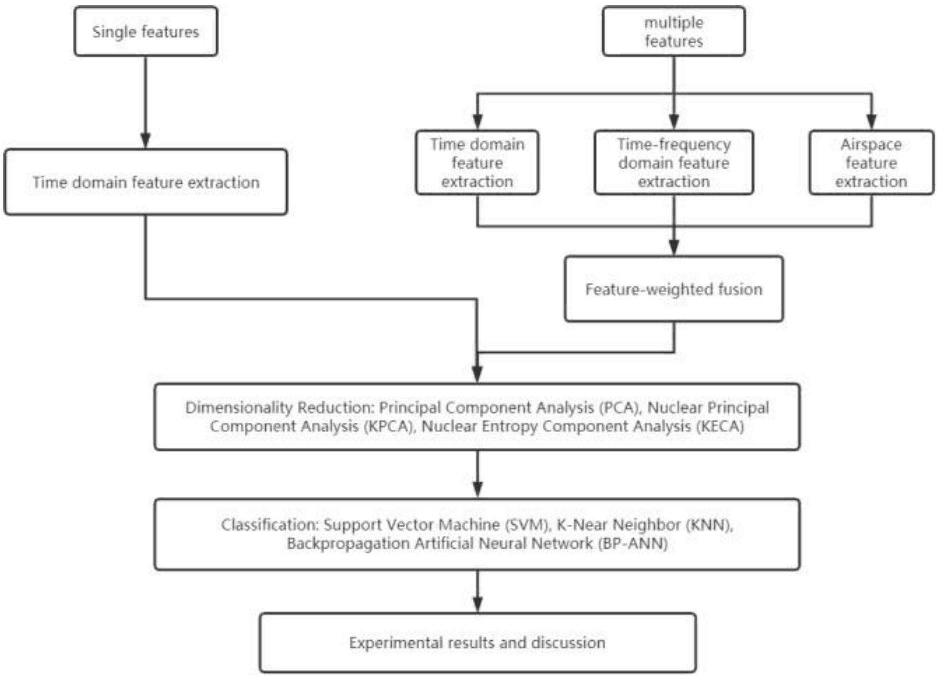

Fig.1. Classification recognition process for different feature domain

Bionic breath sampling has the following characteristics: 1) multi-stage sampling, sampling results show a cumulative trend; 2) fast sampling, compared with the classical dynamic sampling, bionic breath sampling time is shorter, so it cuts down the contact time between the sensor and the gas, relieves the pressure of sensor cleaning and reduces the possibility of sensor poisoning; 3) has a variety of feature information, in the information collection process, each segment contains transient characteristics and steady-state characteristics, and each segment contains information of the three stages of rise, stability and attenuation. This provides convenience for feature extraction. According to the relevant research done by Meng on the basis of this algorithm, the performance of the bionic breathing algorithm is due to classical dynamic sampling, and the designed classifier is smaller and more accurate.

3. Electronic nose detecting

The entire detection process of the electronic nose includes three processes: gas sampling, data processing and cleaning. Among them, data processing is very important. There are common data processing algorithms like K-nearest neighbor algorithm, principal component analysis method, backpropagation artificial neural network, support vector machine, etc., but there are certain shortcomings in the above methods. Before data processing, most of the data are pre-processed, because the gas diffused into the electronic nose system of the sensor array will have a noise. So the filters to are needed eliminate this series of noise interference, median average filtering and Savitzky-Golay (S-G) filtering can be selected, which respectively have a significant effect on the filtering of isolated impulse noise in the hardware circuit and the noise of the sensor response, to make the curve more smooth.

Pei-Feng Qi, Ming Zeng et al. proposed an OCSVM algorithm which is based on SVM optimization to detect the authenticity of liquor.

Optimization model based on OCSVM (Pei-Feng Qi, 2017):

$$\min_{\omega,\xi,\rho} \frac{1}{2}\omega^T\omega + \frac{1}{vn}\sum_{i=1}^{n}\xi_i - \rho \qquad (1)$$

$$s.t.\ \ \omega\cdot\phi\left(x_i\right) \geq \rho - \xi_i \ \ \left(\xi_i \geq 0, i = 1, 2, \cdots, n\right) \qquad (2)$$

Compared to other algorithms, the OCSVM only trains the positive sample. In the process of selecting the optimal parameters of the algorithm, the cross-validation method is used for estimation. And because the algorithm only estimates the positive sample, the classification hyperplane should contain more positive samples to improve the recognition accuracy of the positive and negative samples. As a conclusion, the parameter corresponding to the highest cross-validation accuracy is not the optimal classification parameter. In the experiment of this team, three positive samples and three negative samples were selected, and after data processing, five samples were selected to train the classifier, and the remaining samples were used to detect the authenticity of liquor in subsequent experiments. Experimental results show that the detection accuracy of liquor by the optimization algorithm has been significantly improved. Although the recognition accuracy of positive samples has been reduced, the recognition accuracy of negative samples has been improved a lot, which also effectively improves the detection efficiency of fake wine.

At the same time, there are also some researchers concentrating on classification problems, such as Li Jinjin et al. using an electronic nose to identify and classify by extracting a single feature from a liquor sample, and Wang Qian et al. using an electronic nose to identify and classify by extracting multiple features from a liquor sample after fusion, and both of them came to same conclusion (as shown in Fig.1)

Li Jinjin, Sun Zhehua et al. used electronic noses to identify different types of liquor (principal component analysis method (PCA), nuclear principal component analysis method (KPCA), nuclear entropy component analysis method (KECA)) to compare the dimensionality reduction effect, and also proposed the interclass discreteness and intraclass discreteness. Besides. the feature classification and recognition accuracy of the other three algorithms was compared (support vector machine (SVM), K-near neighbor (KNN) and back-propagation artificial neural network (BP-ANN)). The results show that the corresponding dimensionality reduction effect of KECA is significantly better than that of the two external dimension reduction methods. BP-ANN has the highest recognition rate, but the recognition time is longer. And the recognition rate of KNN is also not low, but the recognition time is significantly less than that of BP-ANN. Overall, the classification effect of KNN is the best.

Wang Qian, Meng Qinghao and others also used the electronic nose to carry out algorithm research on liquor classification, the difference is that Li Jinjin et al. only studied the time domain characteristics, while Wang Qian et al. studied not only the time domain, but also the time frequency domain and the air domain. The three types of features are fused and then used for identification and classification. In the process of feature fusion, in order to avoid feature redundancy, features with higher separability are given higher weights, and the corresponding weight is determined according to the divisible degree of the features, Finally, according to the experimental results of his team, the same experimental results as Li Jinjin's team were obtained. The KECA algorithm had the best dimensionality reduction effect, the recognition accuracy of BP-ANN was higher, but the recognition time was longer, while the recognition accuracy of KNN was slightly lower than that of BP-ANN, and the recognition time was significantly lower than that of BP-ANN. So whether it was recognition under single domain or multi-feature fusion, KNN algorithm should be used for recognition classification.

Wang Jie, Tao Yang, Liang Zhifang and others proposed an extreme learning machine based on particle swarm algorithm and artificial bee colony algorithm (PSOABC—ELM) to solve the problem that the detection of gas pollutant concentration by electronic nose cannot achieve the ideal accuracy. The experimental results show that the detection accuracy of the algorithm is higher, the error is smaller, and the stability is stronger when detecting the concentration of gas pollutants, which proposes new ideas and methods for gas detection using the electronic nose in the future.

4. The application of electronic nose

Electronic nose is mostly used in the detection of food, such as the aforementioned Qinghao Meng teacher’s team for the detection of liquor. Liquor occupies an important position in China's economy, the authenticity of liquor and quality problems are concerned. And there are also other foods in various aspects of the detection or identification. Such as the classification of onions, Guoqin Li, Yanru Huang and others used electronic noses to detect volatile substances of purple skin onions, yellow skin onions and white skin onions extracts. Combined with the BPNN algorithm, the volatile substances corresponding to different onion extracts can be identified, which provides certain technical support and theoretical basis for better preservation and application. As for the problem of food preservation, Yuantao Chen, Yizhou Xiong and others used electronic nose to detect the freshness of food samples of fruit, vegetable and meat. The sample data were identified by linear discriminant analysis model, support vector machine model and convolutional neural network model. As a result, the accuracy of convolutional neural network model was the highest, and the electronic nose system based on deep learning can make an objective evaluation of the freshness of food and improve the accuracy of food freshness judgment. Ferdy Erlangga, Dedy Rahman Wijaya et al. used electronic nose and neural network algorithms to detect whether rice was expired, and the results showed that the accuracy reached more than 99%, which could correctly determine the quality of rice; Talha Anwar, Hassan Anwar used sensors in the electronic nose to detect the odor of extracted beef, and divided the results into fresh, semi-fresh and spoiled three categories.

Electronic nose is not only used in food detection, but also has a good effect on pollutant detection. The Santago Marco team of Spain Catalonia Bioengineering Research Institute researched an electronic nose which can work with a UAV, in order to detect sewage discharge better, which can achieve real-time monitoring of gas emission concentration and prediction in the sewage plant and transmit data to the management department for management; Weiling Liu, Lei Kang and others used the electronic nose to design a set of equipment that can detect odorous pollution gases in the environment. And the equipment can detect different polluting gases by different sensors, which has strong flexibility and high practical value.

Electronic nose also has high application value in medicine, Yanyi Lu, Lin Zeng and others used electronic noses to detect and identify the thiol acetate (TH) culture medium and pure culture solutions of Acinetobacter baumannii, Escherichia coli, Klebsiella pneumoniae, Staphylococcus aureus, pseudomonas aeruginosa, and Pseudomonas aeruginosa, which combined with BP neural network algorithms on a single bacterium recognition rate of more than 90%, to draw the conclusion that the electronic nose can be used to quickly detect and identify wound infection bacteria. Maimunah, Mukhtar Hanafi et al. used electronic noses to distinguish between several herbal raw materials in Indonesia, such as empon-empon, galangal, and turmeric, and the experimental results showed that deep neural networks can classify raw materials according to odor, with an accuracy rate of 86%.

At present, the electronic nose is not only portable for using alone, but also used with other technologies for detection. Jinjin Li, Qian Wang and others studied the portable electronic nose for the gas single domain and multi-domain feature fusion. Zhiming Guo, Junyi Wang and others used machine vision, electronic nose, near-infrared spectroscopy and a series of technologies to detect whether fruits and vegetables were of poor quality in the storage or transportation process, so as to be able to reduce certain economic losses in time; Jinyan Zhu used electronic nose, the electronic tongue and colorimeter to measure the anthocyanin content in blueberry juice, and establish a backpropagation neural network model to predict the anthocyanin content. The results proved that the algorithm has certain reliability for content prediction, which provides a new way for future research; Yao Feng et al. used electronic nose and live cell sensors to detect the number of live cells and products in real time during ethanol fermentation, laying a certain foundation for detecting important parameters in similar fermentation processes in the future; Yijun Shi, Hongtao Wu et al. designed a wireless electronic nose system. The system uses near-infrared spectral absorption detection technology, principal component analysis and backpropagation neural network for data processing. Experimental results showed that the electronic nose system needs to be trained more than 1,000 times to achieve stability. The accuracy of the identification of vinegar and vinegar products such as fruit vinegar white vinegar reached 100% accuracy, achieving the goal of high precision and high accuracy and providing a new direction for future development, which has good application prospects.

5. Conclusion

Since electronic nose was proposed formally in 1994, it has been widely used in various fields. How the electronic nose can be combined with drones to achieve more difficult operations in places that people cannot reach is a direction of current research. For example, real-time monitoring of its pollution concentration in heavy industrial areas, searching for possible explosion sources in explosive areas, etc. It is impossible to only use an electronic nose to complete these tasks. However, when combined with other technologies, whether it can achieve better cooperation without reducing its own use efficiency needs to be further studied. Most of the current research on electronic noses focuses on food-related detection, and there are fewer studies on industry, environmental pollution, medical treatment, etc., These scenarios have higher requirements for the electronic nose, not only high accuracy, but also the size and sensitivity of the electronic nose are all factors that should be considered. All in all, future research on electronic noses needs to be more thorough.

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