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Research on Chemical Constituents of Apple Odour and Design of Its Identification System

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Odour is an important quality factor in the selection of the apple. How many chemical constituents are there in apple odour and how to quickly detect them is a subject in food, gardening and computer science. With the development of sensor, network communication and embedded computer technology, the electronic nose research becomes a hot topic. The chemical constituents of odours from different apple cultivars were studied in this paper. It is showed that the smell of fresh, good quality apple, the content of the chemical constituents is balanced. According to the characteristics of apple odours, it carries on exploratory research for the apple odours detection as the apple quality identification basis. It designs a portable apple odour detection system with six SnO_2 gas sensors as its odour collector and TMS320VC5402 as its processor. There is other hardware such as high precision A/D converter MAX1403, a 3 * 5 keyboard, and LCD in the system. It introduces interface circuit DSP to A/D converter and keyboard with the characteristics of different varieties of apples odours. A BP neural network is applied in the pattern recognition of apple odours. It studies on the extraction method of characteristic value, the improving for BP algorithm, the BP neural network transplanting to DSP platform. This system can automatically identify apple odour and its application will provide a new method for apple quality identification.
Keywords: Apple odour; Chemical constituents Gas sensor; TMS320VC5402; Electronic nose; Pattern recognition

1. Introduction

Apple has always been an important fruit in the world, and it is identified as one of 11 kinds of superior agricultural products by Ministry of Agriculture in China. There are many indicators for apple division, and the basic quality requirements ,in fresh apple grading standards in China, is the full fruit, fresh and clean, no abnormal smell or taste, fully developed, with good maturity for sale or storage. It is visible that smell plays an important role in the characterization of the apple (Jiewen Zhao and Xiaobo Zou,2004). However, due to the complex composition and the sensory organs subjective effects, odor is more difficult to identify than other characters of apple, which has become focal and difficult points in research. At present, the electronic nose system, which uses odor sensor array to collect data and PC to process data, has been successfully tested and applied. This article describes a portable apple odour detection system.

2. System design scheme

The system consists of the following components: odour sensor array, data acquisition module, the control module for device, information display module and the processing system with DSP core. Data processing is: odour signals that acquisition device obtained is pre-treated and then A/D conversion; after the signal feature extraction, signal is input to the processor DSP in the form of a digital matrix; the digital matrix is computed and processed by the processor according to the relevant instructions, and finally display the results on the LCD screen. Apple quality level tentatively scheduled for three levels, the good, bad and disabled. Figure 1 shows a block diagram of the system.

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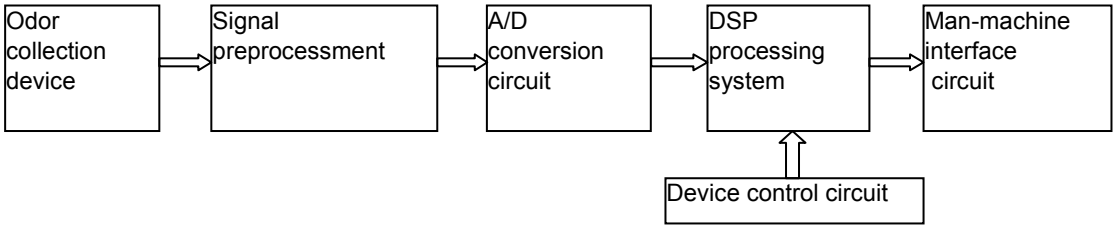

Figure 1 Block diagram of the system for apple odour research

TMS320VC5402 core device is the TI Company's mainstream products. C5000 DSP platform is particularly suitable for portable products, and VC5402 is the higher cost of fixed-point digital signal processors (Mingzhen Dai and Jian-jiang Zhou, 2015).

3. Hardware design for odor acquisition

3.1 The design of odor collection chamber

Apple odour generally composes of ethylene, formic acid, acetic acid, propionic acid, butyric acid, octanoic acid and other volatile acids and esters thereof, methanol, ethanol, acetaldehyde, etc. based on food chemistry research, and therefore chooses sensors which are sensitive to these gases to make up sensor array. This design uses six thick metal tin oxide sensors (TGS800, TGS822, TGS824, TGS825, TGS2602, TGS2610) which are produced by Figaro company in Japan. Each sensor in sensor array has a different sensitivity to the smell test, TGS2602 sensitive to toluene, ethanol and TGS822 more sensitive to alcohol (China Sensor Technology Network, 2003).

When the surface-sensitive layer of SnO_2 gas sensor contact with air, oxygen in the air is adsorbed onto the surface of the sensitive layer by the electron affinity of the molecule and get electrons from a surface of the semiconductor to form O_{2-}, O-, O_{2-} and other acceptor-type surface level, in the result of surface resistance increasing; if a reducing gas such as H_2, CO gas is detected as being in contact with the surface, the redox reactions is happened, and the surface resistance drops with oxidizes the trapped electrons returned to the semiconductor. It can detect the gas used of changes in surface resistance of gas sensors. The above-described process can be described in three chemical reaction formulas:

$$\frac{1}{2}O_2 + ne \rightarrow O^{n-}_{\text{adsorption}} \quad (1)$$

$$O^{n-}_{\text{adsorption}} + H_2 \rightarrow H_2O + ne \quad (2)$$

$$O^{n-}_{\text{adsorption}} + CO \rightarrow CO_2 + ne \quad (3)$$

Where: e ------ electron charge

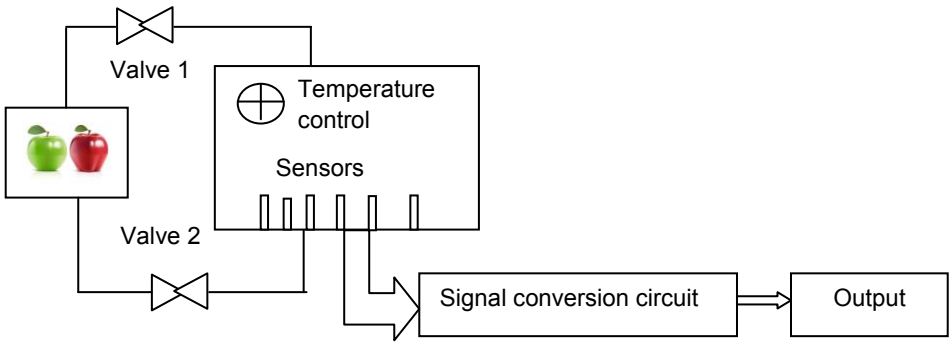

Figure 2 The schematic of odour capture device

In addition, if there are structural dislocations in the portion those semiconductor die contacts with, it would form barrier at the point of dislocations that can hinder movement of carriers, which changes its height and the gas sensor resistance. Due to the difference of the sensitive material, the thickness of the sensitive layer, doped with rare metals, the heating and operating temperatures, ambient temperature and humidity and other

conditions, various sensors are sensitivity to different gas molecules.The test apparatus for odour acquisition is shown in Figure 2. Apple is placed in a semi-closed container, called resettlement room. The sensor array is placed in a reaction chamber, the volume of which is as small as possible, and temperature control equipment is installed in it. In order to save space, six sensors are arranged in line. In order not to distribute to other odour, the reaction chamber is made of stainless steel. Valve 1 and valve 2 are the intake and exhaust ports.
Due to the limited space of the reaction chamber, the volume of temperature control equipment cannot be too large. By comparing the advantages and disadvantages of microcontroller-based temperature control circuit and artificial circuit for temperature control equipment, it chooses the artificial circuit. The reason is that its size is small and can set up flexible drive power, although the accuracy of artificial circuits is lower than microcontroller-based temperature control circuit.

3.2 The design of core processing circuit

The resistance values of sensor are difference in the case of different gas concentrations sensor. According to this feature, the resistance value can be converted into a continuous signal by the voltage value conversion circuit, and these voltages can be approximated representation of the original odour signal. There are N sensors in the gas sensor array, so that if the sensor array is used to measure M-gas, the response of the sensor array is M random process collection according to the M gases. It can be described in the formulas:

$$E(t)=\begin{bmatrix} \xi_{11}(t) & \xi_{12}(t) & \cdots & \xi_{1M}(t) \\ \xi_{21}(t) & \xi_{22}(t) & \cdots & \xi_{2M}(t) \\ \cdots & \cdots & \cdots & \cdots \\ \xi_{N1}(t) & \xi_{N2}(t) & \cdots & \xi_{NM}(t) \end{bmatrix}, \quad t \in T \tag{4}$$

As can be seen from the data output the sensor array, the data processing cannot be accomplished by simple data calculations. Before processing and analysis of the data, it must convert the artificial signal into digital signal which collects by the sensors, that is A/D conversion. Because the signals are low-frequency small-signal and the high accuracy requirements for data processing system, the precision is must be considered in the choice of A/D converter. MAX1403 produced by MAXIM Company has the features of high precision, multi-function, low power consumption, and it can provide conversion results through the serial digital interface. When the master clock frequency is 2.4576MHz or 1.024MHz, the on-chip digital filter can process line frequency and associated harmonic frequencies, and set the magnitude of these frequencies to zero, so that it can get better filtering effect without external filter. At the same time, it also helps to improve the quality of the digital signal output from the A/D converter.
This design uses TMS320VC5402 DSP as the core device. TMS320C5000 DSP platform is the TI Company's mainstream products, and C5000 DSP platform, which is particularly suitable for personal and portable products, is most popular in the digital consumer markets. C54x DSP is currently the mainstream products in application, because of its high performance and low cost. VC5402 is the higher cost of fixed-point digital signal processors launched in October 1999.
For ease of viewing the test results, this design makes a man-machine interface circuit in hardware. It includes a parallel interface, keyboard circuit, the liquid crystal display circuit, RS232, FLASH memory and RAM memory. It designs a 3 × 5 matrix keyboard. Due to the limited resources of TMS320VC5402 chip I/O port, it expands into the latch 74HC573 I/O port to form non-coding keyboard. Specific definitions of key codes include data acquisition and transmission control, scroll up and down and clear the screen, data storage and other functions.

3.3 Experimental procedure and Phenomenon

Experimental procedure for the experimental device designed as follows:
(1)Open the valve 1 for holding ventilation, and open the temperature control switch in the reaction chamber, and then wait 2 minutes.
(2)Close the valve 1, open the valve 2, and apple is moved into the sample gas generation chamber, sealed to wait 5 minutes to step 3.
(3)Open the collection procedures to begin collecting data.
(4)Shut off the valve 2, and it is the time for response between gas sample and the sensors.
(5)Stop the acquisition program, and open reaction chamber to remove the apples. The reaction chamber is sealed five minutes to restore.
(6) The next test.

Tests under the following three conditions: the reaction chamber is empty, put into an apple that general maturity, and put into a rotten apple. The output voltage waveform of sensors measured is shown in Figure 3,4and5.

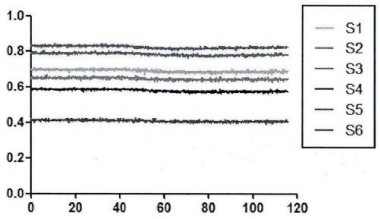

Figure 3 Sensor array response profiles of background air

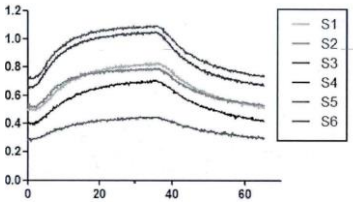

Figure 4 Sensor array response profiles of an apple that general maturity circuit

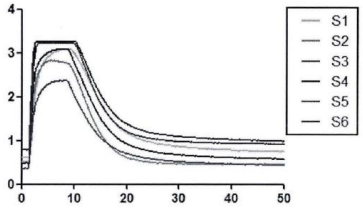

Figure 5 Sensor array response profiles of a rotten apple

The above test results show that SnO2 gas sensors have clear response to apple odours. With the improvement of maturity, the odour concentration has a greater change, so that the response voltage from sensors for the smell concentration of rotten apples quickly reaches their peaks (Chenxing Chen, 2015).

4. Odor Recognition Based Neural Network

4.1 Pattern Recognition Model

According to the data that identify an apple either good or bad is called apple odour pattern recognition. Pattern recognition are generally divided into supervised and unsupervised pattern recognition system. For this design, the data experimental samples have been identified, and therefore it belongs to supervision pattern recognition. Identification process is divided into decision-making phase and design phase, like Figure6.

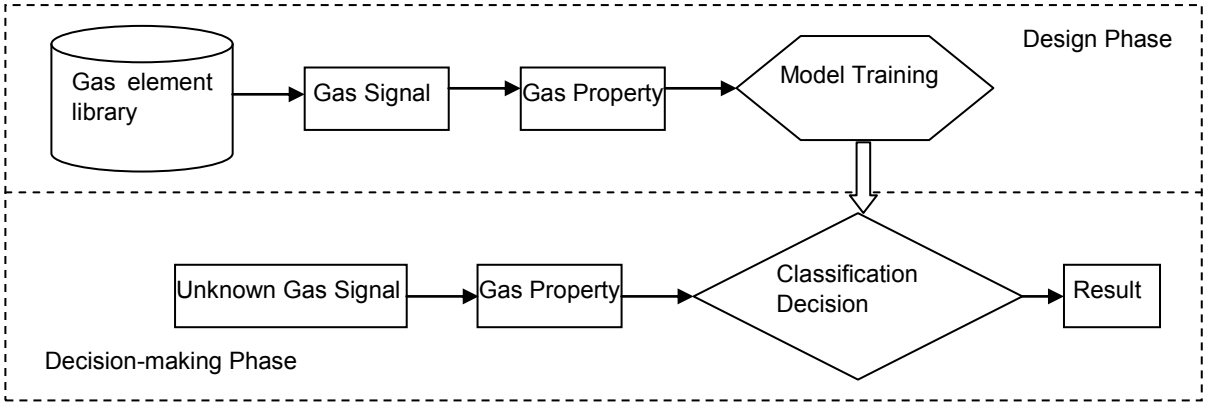

Figure 6 The block diagram of pattern recognition system for gas

According to Figure6, the sensor devices collect apple odours to transform and convey it into the DSP; as a result, it become digitized time-series signal. Then, it is pre-treated such as normalization in order to divide it into a number frames, according to a certain time window, or actual needs and algorithms. This step can turn a continuous signal into relatively isolated elements as the basic unit of recognition. The next step is feature extraction. Each frame signal is extracted into a feature vector as pattern recognition sample after a certain signal processing, and task of the system is to identify which one in gas element library related to the samples.

4.2 BP neural network implemented on DSP platform

BP algorithm's idea is: make squared error of the sample between output as desired and actual output as a criterion function, use the gradient descent method, starting from the output layer, correct weights layer by layer so that the criterion function minimum. [7] The entire network consists an input layer, a hidden or more than one layer and output layer. There is connection between adjacent layers, but no connection between the inner layers, and the output of the previous layer is the input of the next. Characteristics of the entire network depend on the threshold between adjacent neuron connection weights and neurons.

(1)Design input and output layer

The input layer is equal to the number of sensors, and output layer is equal to the number of recognition results. This design has six sensors, so the input six; results are three, which is raw, ripe and rotten.

(2)Select the number of hidden units

If there are too few hidden units, network training requirements may not be achieved, or the trained network is not strong enough, and it has a poor fault tolerance. But if there are too many hidden units, learning time will be too long; the deviation is not necessarily the best, so there is an optimum number of a hidden unit. It can select the number of hidden layer units according to the following several formulas (Kaidi Cao, 2015).

$$k < \sum_{i=0}^{n} C(\begin{matrix} n_1 \\ i \end{matrix}) (n_1 \geq i) \tag{5}$$

$$C(\begin{matrix} n_1 \\ i \end{matrix}) = 0 \quad (n_1 < i) \tag{6}$$

Where k is the number of samples, n1 is the number of hidden units, n is the number of input units.

$$n_1 = \sqrt{n+m} + a \tag{7}$$

$$n_1 = \log_2 n \tag{8}$$

Where n the number of input units, n1 is the number of hidden units, m is the number of output units, a is a constant between 0-10.

For function approximation of BP neural network, the number of hidden units is related to the functions and their precision to be approached.

(3) Select the value of initial weights

Due to the nonlinearity, there is a great relationship between the initial value and the learning whether the local minimum or not and whether the convergence. An important requirement is to make the initial weights of each neuron close to zero when enter cumulative, and it will ensure that does not fall on those flat areas at start. Weight generally takes a relatively small random value, so it can ensure that each neuron advances in where their conversion function greatest changing at the beginning (Guiping Wang and Jinzheng Wang, 2015). So it needs to be normalized for input samples.

The network topology is 6-8-3, namely: the input is the signal of the six gas sensors, and the output is the three results. According to the characteristics of the experimental hardware platform and real-time and non-destructive testing requirements, target MSE take 0.01.

(4) Recognition results and error

The expected value of the three kinds of recognition results is as follow.

[1 0 0]-------Ripeness apple,[0 1 0]-------Immature apple,[0 0 1]-------Rotten apple.DSP-based BP recognition results are shown in Table 1.

Table 1 BP recognition results

No.	Actual state	Test Results	Recognition results	No.	Actual state	Test Results	Recognition results
1.	Ripeness	0.99101 0.00524 0.00337	Ripeness	11.	Immature	0.00108 0.99713 0.00214	Immature
2.	Ripeness	0.99532 0.00106 0.00213	Ripeness	12.	Immature	0.00457 0.99201 0.00102	Immature
3.	Ripeness	0.99487 0.00213 0.00145	Ripeness	13.	Immature	0.00723 0.99105 0.00121	Immature
4.	Ripeness	0.99624 0.00009 0.00208	Ripeness	14.	Immature	0.00653 0.99218 0.00054	Immature
5.	Ripeness	0.99356 0.00476 0.00135	Ripeness	15.	Immature	0.00576 0.99312 0.00143	Immature
6.	Ripeness	0.99496 0.00457 0.00132	Ripeness	16.	Rotten	0.00576 0.00004 0.99301	Rotten
7.	Ripeness	0.98335 0.00876 0.00357	Ripeness	17.	Rotten	0.00312 0.00045 0.99445	Rotten
8.	Ripeness	0.99765 0.00008 0.00196	Ripeness	18.	Rotten	0.00463 0.00132 0.99423	Rotten
9.	Ripeness	0.99546 0.00358 0.00215	Ripeness	19.	Rotten	0.00634 0.00057 0.99187	Rotten
10.	Immature	0.00324 0.99574 0.00125	Immature	20.	Rotten	0.00723 0.00034 0.99112	Rotten

According to the experimental results on DSP platform, the simulation experiment is carried out by Matlab. The pre-processed data is trained by writing BP neural network to verify the performance of the sensor array. The network topology is 6-8-3, and target MSE take 0.01. The simulation results are similar to those in Table 1, which shows that it is feasible to use TGS series sensor array under DSP platform. But the simulation results better than before when change the network structure of 8-8-3. Therefore, in order to improve the universality of the recognition object, it is better to increase the redundant information amount properly in the selection of the sensor array.

5. Conclusions

This article describes an apple odour detection system based on DSP and BP neural network. The system includes sample acquisition, A/D conversion, and nonlinear pattern recognition. It uses gas sensors to gather apples odours, via the signal processing and pattern recognition to identify the state of maturity of the apples. The main contents of the thesis include:

(1)Choices gas sensors and its array. It takes six SnO2 gas sensors to make up array, and sets the temperature control system of reaction chamber, and sets air switching equipment between the reaction chamber and outside, and satisfy the gas sensors' requirements of the environmental. Experimental device is designed to capture the odours, and it sets up experimental procedures combined with other hardware circuitry and pattern recognition algorithms.

(2)Design the hardware processing circuit. It uses cost-effective TMS320VC5402 chip as the processor, high precision MAX1403 as A/D converter, and introduces the interface circuit between DSP and A/D converter. Sets a 3*5 keyboard, and introduces DSP and keyboard interface with the different characteristics among varieties of apples. In order to achieve human-computer interaction better, the system design interface circuit between DSP and LCD, and the results can display on the LCD.

(3)Sets pattern recognition system based on the neural network. Research on the software design of BP neural network on the DSP platform, and achieve the porting and testing work on the hardware.

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