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Simulation of Artificial Noses for the Automated Detection and Classification of Organic Compounds

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Abstract-This paper is an introduction of Artificial Neural Networks. Mainly deals with an exciting application of neural network called "Electronic Nose".
The idea behind this application is simple. Electronic/Artificial noses are being developed as the systems for automated detection and classification of odors, vapors and gases. To avoid domestic accidents in the houses, small scale industries or mines by identifying and reporting them in the appropriate time. Electronic Nose is developed as a composition of chemical sensing system and a pattern recognition system. For this we use sensor array or spectrometer and artificial neural network. We are developing Electronic noses for the automated identification of volatile chemicals for environmental and medical, food industries. In this paper, tried to describe the working of Electronic nose and then showed some results from a prototype Electronic nose.
Keywords: Electronic nose, Neural Network, Sensing System, Automated Pattern Recognition System, Spectrometer.

1. INTRODUCTION

Neural Networks are form of Artificial Intelligence that, through pattern matching, predicts the outcome from a given set of inputs. The neural network trains using a pattern file. In training, it converges on a proper set of weights, or coefficients that lead from input/output. After training the network, simply computes an arithmetic expression that is a function of inputs and weight coefficients, to obtain the output.

1. 1 Artificial Neural Network

An Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information. The key element of this paradigm is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements (neurons) working in unison to solve specific problems. ANNs act like people, learn by example. An ANN is configured for a specific application, such as pattern recognition or data classification, through a learning process.

The first artificial neuron was produced in 1943 by the neurophysiologist Warren McCulloch and the logician Walter Pits. But the technology available at that time did not allow them to do too much.

1.2 Advantages of Neural Networks

1. Adaptive learning: An ability to learn how to do tasks based on the data given for training or initial experience.
2. Self-Organization: An ANN can create its own representation of the information it receives during learning time.
3. Real Time Operation: ANN computations may be carried out in parallel, and special hardware devices are being designed and manufactured which take advantage of this capability.

1.3 Neural networks vs. Real computers

Neural networks follow a different approach to problem solving than that of conventional computers. Conventional computers use an algorithmic approach i.e. the computer follows a set of instructions in order to solve a problem. Unless the specific steps that the computer needs to follow are known the computer cannot solve the problem. That restricts the problem solving capability of conventional computers to problems that we already understand and know how to solve. But computers would be so much more useful if they could do things that we don't exactly know how to do.

Neural networks process information in a similar way the human brain does. The network is composed of a large number of highly interconnected processing elements (neurons) working in parallel to solve a specific problem. Neural networks learn by example. They cannot be programmed to perform a specific task. The examples must be selected carefully otherwise useful time is wasted or even worse the network might be functioning incorrectly. The disadvantage is that because the network finds out how to solve the problem by itself, its operation can be unpredictable.

On the other hand, conventional computers use a cognitive approach to problem solving; the way the problem is to solved must be known and stated in small unambiguous instructions. These instructions are then converted to a high level language program and then into machine code that the computer can understand.

These machines are totally predictable; if anything goes wrong is due to a software or hardware fault. Neural networks are not in competition with conventional computers but complement each other. The tasks are more suited to an algorithmic approach like arithmetic operations and tasks that are more suited to neural networks.

A large number of tasks require systems that use a combination of the two approaches in order to perform at maximum efficiency. Neural networks do not perform miracles. But if used sensibly they can produce some amazing results.

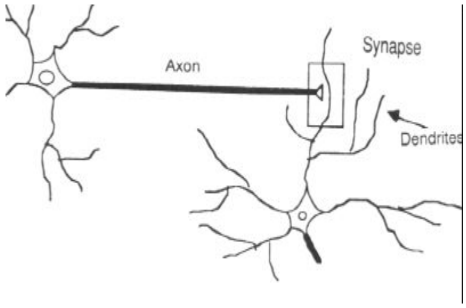

Fig. 1. NEURON

1.4 Artificial Neuron

We first try to realize the essential features of neurons and their interconnections. Then only program a computer to simulate these features. Because our knowledge of neurons is incomplete and our computing power is limited, our models are necessarily gross idealizations of real networks of neurons.

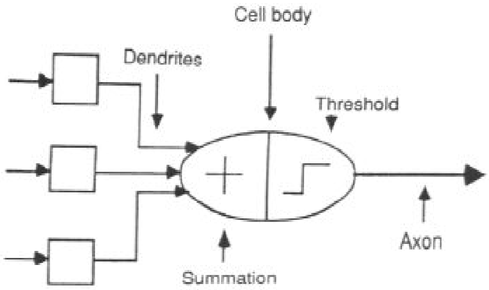

Fig. 2. Neuron Model

1.5 Simple neuron

An artificial neuron is a device with many inputs and one output. The neuron has two modes of operation; the training mode and the using mode. In the training mode, the neuron can be trained to fire (or not), for particular input patterns. In the using mode, when a taught input pattern is detected at the input, its associated output becomes the current output. If the input pattern does not belong in the taught list of input patterns, the firing rule is used to determine whether to fire or not.

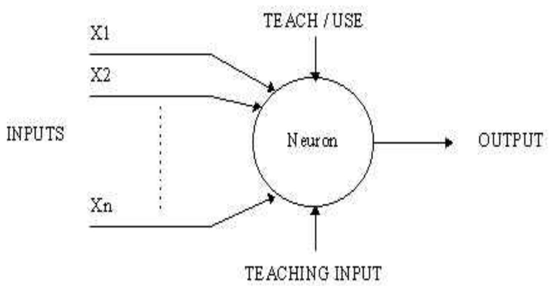

Fig. 3. A Simple Neuron

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2. ELECTRONIC NOSE

An Electronic Nose is a system that uses the pattern of responses from an array of gas sensors to examine and identify a gaseous sample.

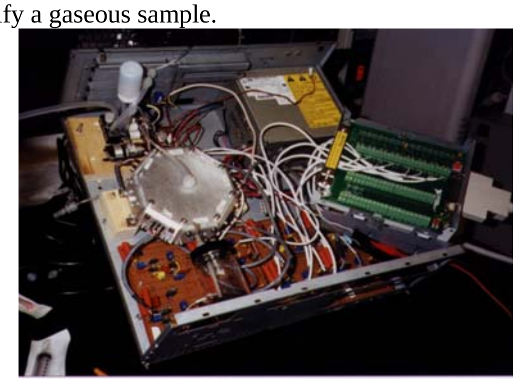

Fig. 4. Electronic Nose

2.1 Analogy between the electronic nose and the biological nose

Inhaling ⇒ Pump
Mucus ⇒ Filter
Olfactory Epithelium ⇒ Sensors
Binding with Proteins ⇒ Interaction
Enzymatic Reactions ⇒ Reaction
Cell Membrane Depolarized ⇒ Signal
Nerve Impulses ⇒ Circuitry & Neural Network

2.2 Biological nose working mechanism

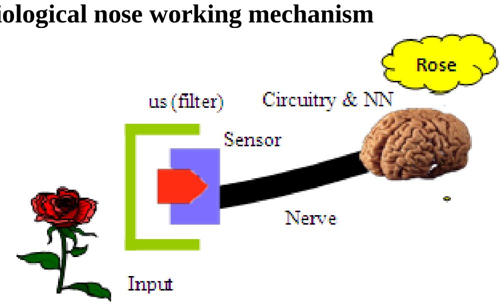

Fig. 5. Biological nose working mechanism

Biological nose smelled then human neurons identified and compared, analyzed with the available data. Got the result.

2.3 Basic design of an Electronic nose

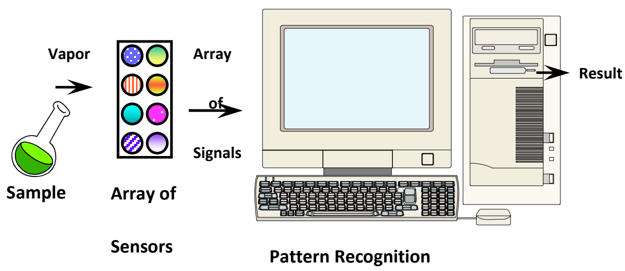

Fig. 6. Basic design of an Electronic nose

The procedure begins with the vapor of the sample. Here we have some array of sensors. They send signals to the system. Pattern recognition starts. When match got found we will get the result.

3. COMPONENTS AND APPLICATIONS OF ELECTRONIC NOSES

The two main components of an electronic nose are the sensing system and the automated pattern recognition system. The sensing system can be an array of several different sensing elements (chemical sensors), where each element measures a different property of the sensed chemical, or it can be a single sensing device (spectrometer) that produces an array of measurements for each chemical, or it can be a combination.

Each chemical vapor presented to the sensor array produces a signature or pattern characteristic of the vapor. By presenting many different chemicals to the sensor array, a database of signatures is built up. This database of labeled signatures is used to train the pattern recognition system.

The goal of this training process is to configure the recognition system to produce unique classifications of each chemical so that an automated identification can be implemented. The quantity and complexity of the data collected by sensors array can make conventional chemical analysis of data in an automated fashion difficult.

One approach for the chemical vapor identification is to build an array of sensors, where each sensor in the array is designed to respond to a specific chemical. With this approach, the number of unique sensors must be at least as great as the number of chemicals being monitored. It is both expensive and difficult to build highly selective chemical sensors. Artificial neural networks (ANNs), which have been used to analyze complex data and to recognize patterns, are showing promising results in chemical vapor recognition.

When an ANN is combined with a sensor array, the number of detectable chemicals is generally greater than the number of sensors [1]. Also, less selective sensors which are generally less expensive can be used with this approach. Once the ANN is trained for chemical vapor recognition, operation consists of propagating the sensor data through the network. Since this is simply a series of vector- matrix multiplications, unknown chemicals can be rapidly identified in the field. Electronic noses that incorporate ANNs have been demonstrated in various applications.

Some of these applications will be discussed later in the paper. Many ANN configurations and training algorithms have been used to build electronic noses including feed-forward networks; fuzzy ARTmaps; Kohonen's self-organizing maps (SOMs); learning vector quantizers (LVQs); Hamming networks; and Hopfield networks.

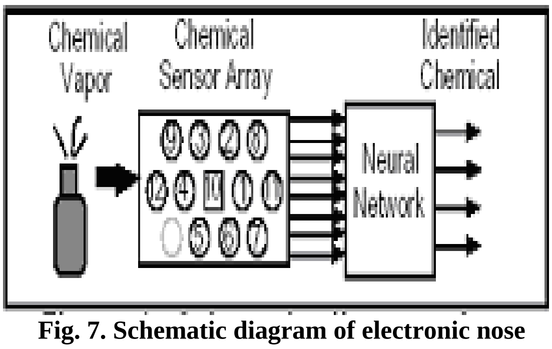

Fig. 7. Schematic diagram of electronic nose

3.1 Prototype Electronic nose

Prototype electronic noses are composed of an array of nine tinoxide vapor sensors, a humidity sensor, and a temperature sensor coupled with an ANN. Two types of ANNs were constructed for this prototype: standard multilayer feed-forward network trained with the backpropagation algorithm and fuzzy ARTmap algorithm [2]. During operation a chemical vapor is blown across the array, the sensor signals are digitized and fed into the computer, and the ANN (implemented in software) identifies the chemical. This identification time is limited by the response time of the chemical sensors, which is seconds. This prototype nose has been used to identify common household chemicals by their odor [3].

Fig.8. Photograph of the prototype electronic nose

The nine tin-oxide sensors are commercially available Taguchi-type gas sensors obtained from Figaro Co. Ltd. (Sensor 1, TGS 109; Sensors 2 and 3, TGS 822; Sensor 4, TGS 813; Sensor 5, TGS 821; Sensor 6, TGS 824; Sensor 7, TGS 825; Sensor 8, TGS 842; and Sensor 9, TGS 880). Exposure of a tinoxide sensor to a vapor produces a large change in its electrical resistance. The humidity sensor (Sensor 10: NH-02) and the temperature sensor (Sensors 11: 5KD-5) are used to monitor the conditions of the experiment and are also fed into the ANN.

Although each sensor is designed for a specific chemical, each responds to a wide variety of chemicals. Collectively, these sensors respond with unique signatures (patterns) to different chemicals.

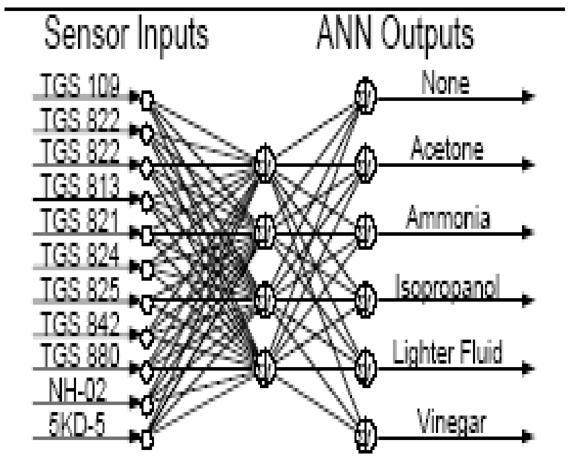

Fig . 9 : Structure of the backpropagation ANN used in the prototype to identify household chemicals

During the training process, various chemicals with known mixtures are presented to the system. By training on samples of various chemicals, the ANN learns to recognize the different chemicals. This prototype nose has been tested on a variety of household and office supply chemicals including acetone, ammonia, ethanol, glass cleaner, contact cement, correction fluid, lighter fluid, methanol, rubber cement and vinegar.
For the results shown in the paper, five of these chemicals were used: acetone, ammonia, lighter fluid, and vinegar. Another category, "none" was used to denote the absence of all chemicals except those normally found in the air which resulted in six output categories from the ANN.

Backpropagation
Architecture: 11-11-6 feedforward
Activation: Logistic Sigmoidal
Learning Rate: 0.10
Momentum: 0.90
No. of Epochs: 1369

Table 1. ANN performance for backpropagation (BP) and fuzzy ARTmap (FA)

Num Train	Num Test	Input substance	% Correct BP	FA
67	28	None	96.4	96.4
75	22	Acetone	100	100
64	14	Ammonia	100	100
93	28	Isopropanol	92.9	100
5	3	Ammonia &Isopr	00.0	66.7
106	25	Lighter Fluid	100	96.0
74	27	Amm & Lig Fluid	100	92.6
66	21	Vinegar	81.0	95.2
68	26	Amm & Vinegar	92.3	76.9
1	2	Isopr & Vinegar	00.0	00.0

Fuzzy ARTmap
Training Vigilance: 0.98
Testing Vigilance: 0.80
No. of Epochs: 3

3.2 Electronic nose for medicine

The sense of smell is an important sense to the physician; an electronic nose has applicability as a diagnostic tool.
An electronic nose can examine odors from the body (e.g., breath, wounds, body fluids, etc.) and identify possible problems. Odors in the breath can be indicative of gastrointestinal problems, sinus problems, infections, diabetes, and liver problems.
Infected wounds and tissues emit distinctive odors that can be detected by an electronic nose. Odors coming from body fluids can indicate liver and bladder problems. Currently, an electronic nose for examining wound infections is being tested at South Manchester University Hospital.
A more futuristic application of electronic noses has been recently proposed for telesurgery. While the inclusion of visual, aural, and tactile senses into telepresent systems is widespread, the sense of smell has been largely ignored. The electronic nose would identify odors in the remote surgical environment. These identified odors would then be electronically transmitted to another site where an odor generation system would recreate them.

3.3 Electronic nose for the food industry

Currently, the biggest market for electronic noses is the food industry. Applications of electronic noses in the food industry include quality assessment in food production, inspection of food quality by odor, control of food cooking processes, inspection of fish, monitoring the fermentation process, checking rancidity of mayonnaise, verifying if orange juice is natural, monitoring food and beverage odors, grading whiskey, inspection of beverage containers, checking plastic wrap for containment of onion odor, and automated flavor control to name a few. In some instances electronic noses can be used to augment or replace panels of human experts.
In other cases, electronic noses can be used to reduce the amount of analytical chemistry that is performed in food production especially when qualitative results will do. It is really a helpful application.

3.4 Electronic nose for environmental monitoring

Enormous amounts of hazardous waste (nuclear, chemical, and mixed wastes) were generated by more than 40 years of weapons' production in the U.S. Department of Energy's weapons' complex.
The Pacific Northwest National Laboratory is exploring the technologies required to perform environmental restoration and waste management in a cost effective manner. This effort includes the development of portable, inexpensive systems capable of real-time identification of contaminants in the field. Electronic noses fit this category. Environmental applications of electronic noses include analysis of fuel mixtures [4], detection of oil leaks [5], and testing ground water for odors.

3.5 Electronic noses for online shopping

These days every body wants to purchase products online. In fact, sitting at home only want to check, order, and enjoy. They simply need E-Nose. Just click on desired perfume image, feel the aroma with the help of this E-Nose at home only. Check it and order it.

3.6 Electronic noses in military, Space and Mines

This device can be used to detect explosives. If it is designed efficiently it can not only detect the explosive but also it can say the amount of destruction it can cause along with the deactivating procedure. Sniper dogs can be replaced with this device to cut-short the investment on them. In mines this device can be used to detect poisonous gases.
To analyze the chemical compositions, the sample of the identified chemical has to be carried from the space to the earth. But by using this device we can carry our analysis from there it self just by placing the device there. By this the future analysis can also be continued with one time investment.

4. PROTOTYPE GRAPH

This is a prototype graph. Here we are taking 2 samples from rose and sunflower. X-axis we have time in minutes. On Y-axis we are taking the aroma released by these flowers in the units of intensity per square meter.

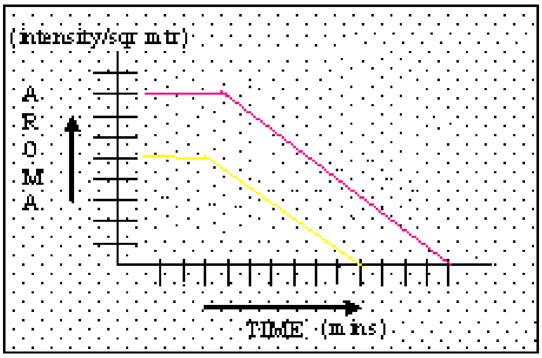

Fig . 10. Prototype Graph

5. CONCLUSION

Thus an "Artificial Neural Network" is developed to make the computer think like a human brain. And an electronic nose is a device intended to detect odors or flavors. Over the last decade, "electronic sensing" or "e-sensing" technologies have undergone important developments from a technical and commercial point of view. The expression "electronic sensing" refers to the capability of reproducing human senses using sensor arrays and pattern recognition systems.

In this paper we want to conclude that this electronic nose warns us by recognizing the odors depending on the input. So it is always important to update the data with the new invented chemical odors.

One of the major disadvantages of this E-Nose is that its analysis depends on the intensity of the chemical when we want to calculate the quantity per percent of the chemical. So some times it gives unpredictable results with changing distances when used to find the quantity of the chemical/item present. Further analysis in this field is needed to make these devices work consistently with varying distances. It also requires better data management issues to have more data to be used for pattern matching and for pattern recognization.

William Words Warth says that "A Person's Character Can Be Detected By Smelling His Actions and Words". Let's hope for such a greater Electronic Nose to be in action in future for a better livelihood of every one.

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