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An Inexpensive, Portable, and Versatile Electronic Nose for Illness Detect

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Экономичный переносной многопрофильный аппарат «электронный нос» для выявления заболеваний

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Health-care strategies are currently oriented towards non-invasive techniques for an early diagnosis. The chemical analysis seems to be a good answer to accomplish both prevention, a fundamental requirement for an efficient treatment of the disease, and non-invasivity. GC is very accurate but is expensive; its sampling and assaying processes are complicated and time consuming, while its results require expert interpretation. Over the last decade, "electronic sensing" or "e-sensing" technologies have undergone some important developments from both a technical and commercial point of view. Particularly, in recent years, the usefulness of the electronic nose has been clinically proved as an opportunity for the early detection of such diseases as lung cancer, diabetes, and tuberculosis. In this paper, a portable, versatile and inexpensive system for the measurement of gas concentration through a gas sensor array is described. The system uses low cost metal oxide gas transducers and can automatically compensate the values of gas concentration detected according to the current values of temperature and humidity. The device works in slave mode and its acquired and computed data are available by means of a host/slave ASCII serial communication protocol. A host device can periodically require the current values of gas concentration and apply the appropriate algorithms for the detection of the investigated substances.

Key words: Portable system, Electronic nose, Sensor gas array, Clinical diagnosis.

В настоящее время стратегии здравоохранения ориентированы на неинвазивные методы ранней диагностики. Биохимический анализ служит хорошим методом, позволяющим оценить результаты лечения и профилактики. Более точной является газовая хроматография. Преимущество заключается в высокой достоверности результатов. Недостаток этого метода исследования — в его высокой стоимости, сложности исполнения, больших временных затратах и сложности интерпретации результатов. За последнее десятилетие технологии электронного распознавания претерпели некоторые важные изменения как с технической, так и с коммерческой точки зрения. А именно: за последние годы польза аппарата «электронный нос» была клинически доказана для возможности раннего распознавания таких заболеваний, как рак легких, диабет и туберкулез. В этой работе описывается переносная многопрофильная недорогая система распознавания потока выдыхаемого воздуха через преобразователи оксида металла, где используется недорогой газ, и которая может автоматически определить полученные объемы температуры и влажности. Требуемые и просчитанные данные прибора доступны в рамках головного серийного протокола. Головный серийный протокол может периодически требовать текущие показатели — объемы и концентрацию газа для определения подходящих алгоритмов для исследования вещества.

Ключевые слова: переносная система, аппарат «электронный нос», поток выдыхаемого воздуха, клинический диагноз.

1. Introducion

The research of non-invasive techniques for the early diagnosis of diseases is today a topic of considerable importance. Many diseases are highlighted by characteristic odors, which can be detected perceptibly in breath. Breath is fundamentally composed of nitrogen, oxygen, carbon dioxide, water, inert gases, and mixtures of numerous and different compounds in very low concentration. Some of these elements are specific markers of diseases [1]. The number of main compounds contained in the breath is a few hundred, as evidenced by using Gas Chromatography (GC) [2]. As known, GC is accurate but expensive and its results require expert analysis. An economical and portable alternative for the study of the compounds contained in the breath is Electronic Nose (EN), which can also be used as a simple screening method for the early medical diagnosis. Recently EN has been used for the diagnosis of diseases such as lung cancer, diabetes, and tuberculosis [3]. Considerable results on lung cancer [4] and diabetes diagnosis have been obtained using Metal Oxide Sensors (MOS) [5]. With the help of EN the early diagnosis of tuberculosis followed by appropriate treatment will reduce the trouble of tuberculosis [6].

The main advantages of MOS are the cheapness, the quick response and recovery times [7], but the measurement can be inaccurate and strongly influenced by temperature and humidity. For this reason, in the identification of gases acquired from the electronic nose, often are used analysis techniques based on Artificial Neural Networks [8], characterized by good noise immunity.

In this paper, a portable, versatile and inexpensive EN for the measure of gas concentration through a MOS gas sensor array is described. The system uses low cost transducers and can automatically compensate the values of gas concentrations detected, according to the current values of temperature and humidity measured.

2. Material and methods

Our tests have been carried out with the prototype device realized in the Biomedical Instrumentation Laboratory of the faculty of Physics at the Altai State University, showed in Fig.1. It is constituted by eight different gas sensors, one transducer of humidity and temperature, enclosed in an aluminum container in which, through two holes, the exhaled air circulates. Externally there is the control circuit, constituted by a Microchip PIC microcontroller, which digitally converts the measured values of gas concentration of every transducer and eventually computes the temperature and humidity correction. The microcontroller (Microchip PIC18F2520) is a high performance RISC CPU, based on a modified Harvard architecture operating up to 5 MIPS with analog features.

Fig. 1. The prototype of the realized device

The eight gas sensors used to develop the electronic nose system (Henan Hanwei Electronics Co) are mounted on gold contacts and separated by a Teflon plate to minimize chemical reactions between the substances present in the breath and electronic components on the printed circuit board. The sensors are reported in Table 1.

Table 1

Gas sensors used

Sensor	Target gas
MQ-2	General combustible
MQ-3	Alcohol
MQ-4	Natural gas, Methane
MQ-5	LPG, Natural gas, Coal gas
MQ-6	LPG, Propane
MQ-7	Carbon Monoxide
MQ-8	Hydrogen
MQ-135	Air Quality Control

The Hanwey MOS sensors require a simple heating and measuring circuit for functioning. The heating circuit is built inside the sensor and needs to be heated to high temperatures to be sensitive to a particular gas present in the air. In the presence of a detectable gas, the sensor conductivity increases and the measuring circuit converts the change in conductivity to a voltage signal.

Temperature and humidity are acquired by the Sensirion SHT-75 transducer that integrates two sensor elements and signal processing in a compact format providing a fully calibrated digital output. A unique capacitive sensor element is used for measuring relative humidity while temperature is measured by a band-gap sensor. Both sensors are seamlessly coupled to a 14bit analog to digital converter and a serial interface circuit.

The device works in slave mode and its acquired and computed data are available by means of a host/slave ASCII serial communication protocol (RS232-C, 115.2 kbps). A RS232 transceiver is used to interface an external host which operates at RS232-C levels. This is necessary in order to reduce the communication errors and to extend the host/slave distance.

A host device can periodically require the current values of gas concentration, temperature and humidity, usings the commands reported in Table 2.

Table 2

Serial host commands

Type	Command Syntax	Slave Response
Gas concentration request (compensated value)	Vnxxxxcc	Vnvvvvsscc
Gas concentration request (not compensated value)	Gnxxxxcc	Gnvvvvsscc
Temperature request	RTxxxxcc	RTvvvvsscc
Humidity request	RHxxxxcc	RHvvvvsscc

n   : sensor number (1..7)

xxxx : don't care value

cc   : frame checksum (xor of the previous bytes)

vvvv : requested value

ss   : status code of the command ('00' = OK)

In order to verify the reliability of the new device, a procedure in vitro was established to measure and identify the concentrations of gases correctly. The procedure employed a calibrating syringe (Hamilton co., Reno, Nevada) and a series of significant substances present in the breath, which variation is indicative of lung diseases. Table 3 shows these substances with the relative concentrations.

Table 3

Gas sensors used

Substance	Concentration	Producer
Ethanol	95%	FMAIA
Acetone	99.9%	VETEC
Ammonia	27-30%	CAAL
Dimethylacetamide	99.5%	VETEC
Methyl Ketone	99.5%	CAAL
Isopropanol	99.5%	ACS
Methanol	99.8%	SYNTH
Toluene	99.5%	SYNTH

Each volatile compound is injected into the measuring chamber of the EN in three different concentrations (0.5 μL, 1.0 μL, 1,5 μL) and the transducer responses are recorded. The response data will be represented as a relative response [9]:

$$S=(V_M-V_0) / V_M,$$

where V_M is the maximum value of the measured response parameter (voltage) in the presence of the analyte and V_0 is the initial value in the absence of the analyte. At the end of each measurement, a pump cleans the chamber, sucking clean air from the external environment selected by a solenoid valve. Fig. 2 shows the experimental setup.
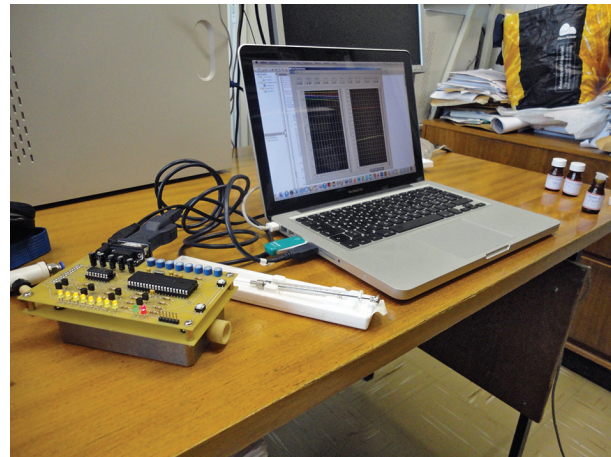

Fig. 2. Experimental setup

3. Results

The results of measures performed at the Faculty of Exact Sciences and Technology of the Pontifical Catholic University of São Paulo (Brazil) are shown in Table 4.

The PCA analysis was applied to reduce the eight-sensor data to a set of two principal component scores aimed to find the factors capturing the largest variance in the dataset. Table 5 shows the result of the PCA analysis rela- ted to the two main components, considering the date relating to the volume of 1.0 μL for injected substances. Figure 3 shows the representation of the main components on the cartesian plane.

Table 4

Measures

	Vol (μL)	S1	S2	S3	S4	S5	S6	S7	S8
Ethanol	0.5	0,378	0,037	0,336	0,238	0,593	0,752	0,079	0,646
	1	0,400	0,035	0,361	0,259	0,662	0,846	0,093	0,632
	1.5	0,443	0,035	0,416	0,284	0,727	0,947	0,100	0,445
Acetone	0.5	0,143	0,018	0,099	0,078	0,087	0,094	0,017	0,042
	1.0	0,423	0,029	0,413	0,275	0,655	0,863	0,095	0,325
	1.5	0,498	0,033	0,478	0,307	0,770	1,008	0,107	0,402
Ammonia	0.5	0,407	0,018	0,365	0,261	0,679	0,799	0,047	0,523
	1.0	0,397	0,035	0,373	0,220	0,577	0,925	0,097	0,366
	1.5	0,343	0,063	0,390	0,245	0,475	0,964	0,145	0,259
Dimethylacetamide	0.5	0,493	0,045	0,424	0,258	0,669	0,970	0,101	0,302
	1.0	0,282	0,019	0,270	0,170	0,397	0,606	0,060	0,231
	1.5	0,223	0,014	0,236	0,147	0,318	0,542	0,072	0,202
Methyl Ketone	0.5	0,692	0,032	0,743	0,456	1,144	1,779	0,204	0,382
	1.0	0,663	0,040	0,673	0,458	1,301	1,849	0,165	0,609
	1.5	0,743	0,037	0,798	0,547	1,392	2,006	0,192	0,574
Isopropanol	0.5	0,462	0,030	0,461	0,293	0,704	0,975	0,110	0,361
	1.0	0,585	0,030	0,631	0,359	0,948	1,380	0,152	0,382
	1.5	0,692	0,024	0,713	0,392	1,056	1,552	0,179	0,412
Methanol	0.5	0,289	0,024	0,293	0,192	0,468	0,661	0,076	0,295
	1.0	0,329	0,026	0,353	0,225	0,570	0,800	0,089	0,328
	1.5	0,362	0,026	0,398	0,250	0,611	0,840	0,099	0,312
Toluene	0.5	0,096	0,005	0,114	0,056	0,084	0,126	0,010	0,041
	1.0	0,170	0,009	0,237	0,147	0,316	0,475	0,074	0,134
	1.5	0,220	0,012	0,310	0,181	0,552	0,819	0,116	0,207

Table 5

PC1 + PC2 (1 uL)

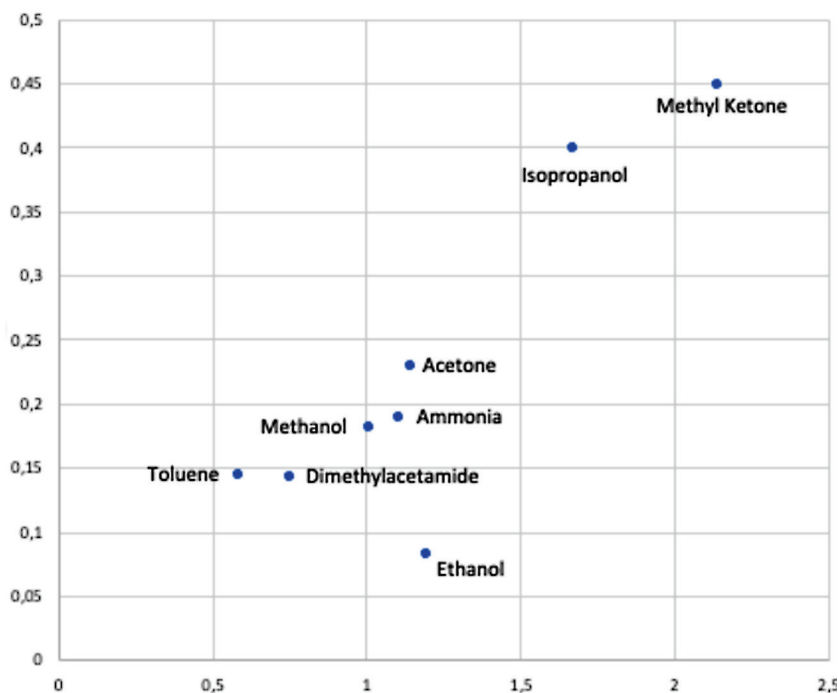|	PC1	PC2
Ethanol	1,195	0,083
Acetone	1,144	0,228
Ammonia	1,106	0,188
Dimethylacetamide	0,755	0,142
Methyl Ketone	2,143	0,448
Isopropanol	1,671	0,399
Methanol	1,007	0,182
Toluene	0,585	0,143

Fig. 3. PCA

4. Discussion and conclusions

Many electronic noses are commercially available today, and they have a wide range of applications, but they are limited applications in breath analysis. E-noses have gradually been used in medicine for the diagnosis of lung cancer. Our simple portable EN, equipped with an array of low-cost MOS sensors, can discriminate in vitro eight fundamental elements present in the human breath. The current investigation is a propaedeutic one for further studies. In the measurements in vivo, to guarantee repeatability, it will be mandatory to compensate the effect of temperature and humidity on sensor response [10] as well as the flow of exhaled breath. In a future study, it may also be interesting to limit the analysis to the exhaled alveolar breath, by measuring the concentration of carbon monoxide. Moreover, our work will extend in the improvement of classification techniques in which we emphasize the importance of evaluating other classification algorithms (as support vector machines or other topologies of Neural Network), as well as the use of different algorithms to select the best subgroup of features for each classifier, instead of using ranking techniques based on statistical tests. The training of the NN will also be done in the presence of noise, since it has been demonstrated that NNs can compensate humidity, drift, and temperature variation phenomenon [11] that affect olfactory signals.

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