"INTELIGENT ELECTRONIC NOSE BASED ON EMBEDDED TECHNOLOGY"

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Abstract— **Recent developments in computer technology have made possible low-cost integration of powerful computers in small volumes. Here we suggest the integration of a small form factor computer for an electronic nose system. This concept allows us to seamlessly implement arbitrary temperature modulation for tin-oxide sensors, remote connectivity, large data storage, and complex signal processing. Electronic artificial noses are developed as a system for the automated sensing and classification of odors, vapors, and gases. We are developing electronic noses for automated identification of easily evaporating compounds chemicals from environmental and medical applications. In this paper, a brief description of an electronic nose is shown and some results from a archetype electronic nose, and discuss applications of electronic noses in environmental, medical, and food industries.**

Index Terms—Single Board Computer, Linear Discriminate Analysis, Graphical User Interface.

I. Introduction

Gases sensors are used in electronic noses which are based on broad selectivity profiles, mimicking responses of olfactory receptors in biological olfactory system. The basic building blocks of a generic electronic-nose systems include sample delivery, sensor chamber, signal transduction and acquisition, data preprocessing, feature extraction and feature classification. In conventional systems, the processing module is a personal computer separated from the remaining parts of the system. This module is responsible for data preprocessing, feature extraction and classification. Significant efforts are required to improve the overall performance of the instrument, and every component mush be given careful consideration. An alternative and effective approach to large sensor arrays is to modulate the operating temperature of a small number of tin oxide sensors. Excitation of the sensor at multiple temperatures during exposure to the analyses is asymptotically equivalent to having a large number of virtual sensors with different selectivity's. However, this solution is not convenient for portable systems, as it requires large memory allocation for each temperature-modulated waveform. In addition, feature extraction becomes more involved than in isothermal DC measurements, increasing the computational load of the computer system.

In terms of signal-processing requirements, all the available options summarized in Table 1 have to be analyzed when designing a temperature-modulated electronic nose system. Considering recent trends in portable computing, the consumption of embedded systems at affordably low cost and size is the most intended solution. This type of systems can be applied not only for mobile devices but also for at-line monitoring, which significantly improves the capabilities of the device. In this article we present an electronics device module based on two design requirements, those are: system signal processing capabilities for temperature modulation of metal oxide sensors and remote operation through network connectivity.

PRESENT THEORY AND PRACTICES

A number of interesting benefits are provided by using embedded system such as abstraction availability of layers for signal acquisition and an operating system via control, high level programming of signal processing algorithms, solid state disks store large data, Ethernet connectivity for commercial off the shelf hardware , serial ports, hardware availability for interfacing various types of displays, etc. The essential use of this implementation is based on an embedded computer system PC/104 standard [5].This consortium helps defining compact size self stacking modules (3.6 x 3.8 in) and PCI bus across stack. Sufficient Input to Output control e-nose and acquired signals are provided by a small data-acquisition and relay board provided. A Single Board Computer (SBC) is based on an Intel code compatible processor

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which allows developing codes on personal or desktop computers debugging and testing is cab be easily done. Wide varieties of operating systems are available, which also includes Microsoft NT embedded system, Windows CE, or open source UNIX clone Operating system (e.g., FreeBSD, GNU/Linux [6]. Availability of source code results in selection of open source option, developer is allows to customize the operating system in order to meet with the hardware constraints.

Figure 1 shows overview of the whole design. Three sensor modules can be control by an instrument. Four metal oxide sensors are contained in each module; one is temperature sensor and signal conditioning, excitation electronics on custom printed circuit board (PCB). On PCB sensors and a stainless steel chamber are mounted directly. An electronic interface can be made by various commercial sensors, including FIS, FIGARO, MICROSENS, MICS or CAPTEUR via configuration jumpers, even though in the current archetype only FIS sensors are used. Over a coil a micro bead sensing material is deposited which is based on internal structure of sensors (SB series).A fastest thermal response of modulating heater voltage is provided by this structure of the sensors , and a very practical feature for the purpose of increasing sample throughput.

The flow injection system consists of a multi-channel manifold with one electro-valve for each intake port is provided. Both order and aperture of each valve and the pump is controlled by the software, as per the configuration file. A zero-filter with air cleaning is included in the reference file. To the sensor chamber the output of the manifold is connected directly. By means of a miniature pump connected downstream for the sensor chamber in vacuum mode the system is operated. To prevent the backflow a check valve is placed between the chamber and the pump.

KEY OBSERVATIONS

Recent trends in industrial automation and process control show a progressive increase of embedded computing technology, indicating a migration from proprietary instrumentation networks towards standard Ethernet networks. The idea of providing remote connectivity to an electronic nose is geared towards expanding the market for these instruments for industrial applications and distributed sensing. Our design provides a versatile, re-programmable platform for remote operation. Incoming remote connections processed with a daemon (a background process), are denoted by ***smelld*** in the recent implementation.

If a connection is established, commands can be given to the instrument to perform sampling or training, to get current sensors values, vary heater voltages, control pump and valves, and also re-program the instrument.

Table 1. Summary of available architectures

Architecture	bits / speed / RAM	Pros/cons	Programming	Appropriate Processing
Sensor Array + µC (PIC)	8 bit / 10 MHz / kbytes	Easy, small, low power, Cheaper	ASM / C	Easy algorithms, k-NN, easy NN, mostly trained off-system. Linear classifiers.
SA + µP or DSP	16-32 bit / 20-100 MHz / Mb	Fast Portable RealTime Oriented	ASM / C / C++	Linear matrix ops, (PCA, LDA, PCR, PLS), k-NN, small NN and FIS. Standard Feature Extraction/Selection
SA + Embedded PC	32 bit / 80-233 MHz / Mb	Fast, medium size, Portable, Huge data capacity	Any	Complex Learning algorithms (GA, NeuroFuzzy Systems, Mixture Models, APR). Adv. Feature Extraction/Selection
SA + Desktop PC	32-64 bit / 700MHz /Mb	Fast, medium size, Huge data capacity, Not portable	Any/ Visual	Any

As elaborated in **Figure 2**, these features facilitate the user to execute log analysis, obtain or change internal database parameters, or modify signal processing software of a distributed system of ipNoses

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from any workstation. Although the e-nose system is remotely operated via TCP/IP under client/server architecture, it can also be developed such as to send active signals to external systems (e.g., e-mail the user when samples do not match specifications).

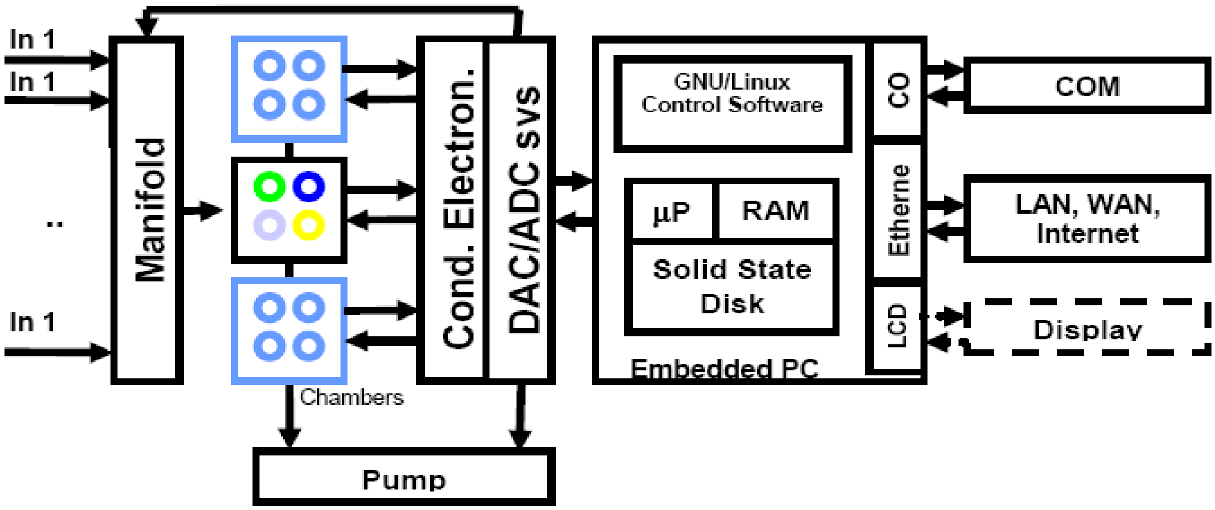

Figure 1. ipNose system overview

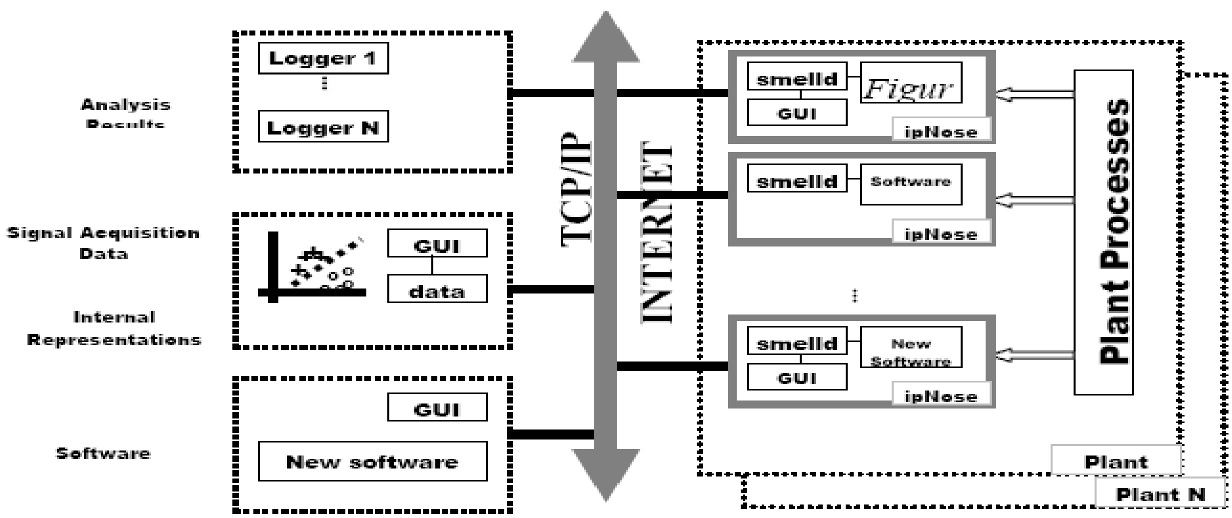

Figure 2. Schematic model for remote connectivity

IMPLEMENTATIONDETAILS

In this section we illustrate the pattern-recognition capabilities of the ipNose. Shown in Figure 3, a database with four odors was collected using a pulsed heater profile on four FIS sensors. Each sample consisted of five cycles, as defined in a sampling-protocol configuration file.

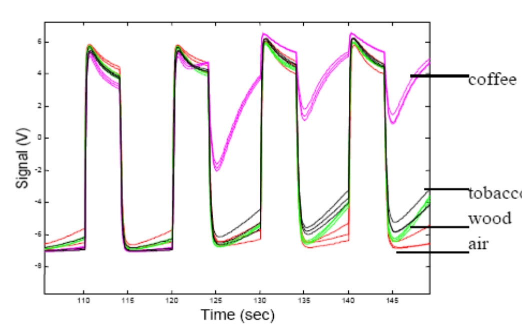

Figure 3. Detail of sample cycle

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A cleaning cycle (e.g., a washing analyte) was first applied to remove volatile compounds from the chamber, followed by two reference cycles (e.g., a zero-filter). The reference waveform may be used to compensate for sensor drift. In the remaining cycles, the target odor was introduced into the chamber and the system was finally purged with filtered air. The database used for this experiment defined a sampling frequency of 8Hz and a 40-second cycle, yielding a 1600-dimensional vector per sensor. The data set was collected for three days using random presentation of the analytes. Rather than using sampling vials, the analytes were "sniffed" directly from their plastic bags by placing the intake close to the surface (3-5cm) without any additional control. In this situation concentration levels may have high variability. Pattern recognition should therefore focus on the shape of the transients rather than their DC offset. For this reason, each waveform was auto scaled. Due to the high dimensionality of the waveforms, a dimensionality-reduction procedure was used. First, principal component analysis (PCA) was used to project the data from the last pulsed cycle (320 samples/sensor x 4 sensors) onto a lower dimensionality feature space (10 dimensions). Linear discriminate analysis (LDA) was subsequently used to project on a three-dimensional space, resulting in the scatter plot as shown in **Figure 4.**

The k Nearest Neighbors voting rule (k=3) was used as a classifier. Since only 17 samples per class were available, predictive accuracy was estimated though leave one out cross-validation. A classification rate of 99% was obtained on the LDA subspace, as opposed to 82% in the original signal space.

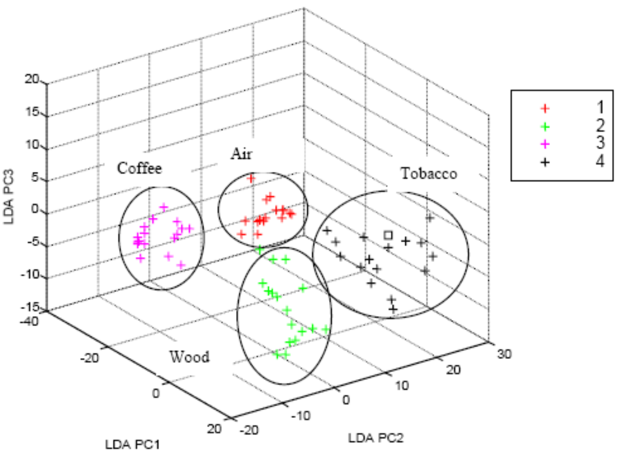

Figure 4. The first three LDA components

CONCLUSION AND FUTURE WORK

In this paper we confronted electronic noses, a system that identifies common household volatile chemicals, and various applications of electronic noses in the environmental, medical, and food industries. The major differences between electronic noses and standard analytical chemistry equipment are that electronic noses tend to produce a qualitative output, it often makes it easier to automate, and can be intended to use in real-time analysis. These results from the archetype electronic nose demonstrate the pattern recognition capabilities of the neural network paradigm in sensor monitoring, especially when the individual sensors are not highly selective. In addition, the archetype presented here has several advantages for real world applications including compactness, mobile, real-time analysis, and automation. Various aspects of the instrument are still under development. The first step is to augment the signal-processing engine, which presently includes LDA feature extraction and kNN classification. Special emphasis will be made to feature generation procedures for temperature-modulated waveforms such as windowed time slicing [7] and feature subset selection [8].A PDA can be used in field tests to control the instrument, for which a graphic user interface is underway. Existing software and hardware are ready for the addition of conditioning modules such as PWM-driven temperature controllers for the sensor chamber and Tenax-traps for thermal desorption.

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