Interface Design Techniques for Electronic Nose Sensors:A Survey

Saeed Samadi
Dept. of Food Biotechnology
Research Institute of Food Science & Technology (RIFST)
Mashhad, Iran
s.samadi@rifst.ac.ir

Abstract—**Electronic nose systems comprise a more or less sophisticated hardware that is incorporated with sensors, electronics, pumps, and flow controller, where the software components ensure suitable technological hardware monitoring, data pre-processing, statistical analysis, and display of processed data. The current paper seeks to survey on interface design techniques for electronic nose sensors, with a specific focus on interface circuit design techniques for signal conditioning of electronic nose sensors. In addition, the paper classifies these circuits into two primary categories: integrated circuits and non-integrated circuits. Lastly, tables are provided to compare frequent methods used and specific application of the e-nose.**

Keywords- Electronic nose; Sensor; Interface; Circuit

I. Introduction

Electronic noses incorporate an array of chemical sensors that have varied specificities. They simultaneously respond to the volatile chemicals present in a gas sample [1]. According to recent researches, these sensors have cognitive ability based on human-computer interaction by means of sensor information processing. This makes researches related to this technology to employ a convergence of electronic, mechanical, and chemical engineering research [2]. Therefore, the entire performance of an e-nose system largely relies on the individual effectiveness and performance of its constituent features [3]. This implies that careful selection and design of frontal nose signals at the posterior of the conditioning circuit is of critical significance if optimum performance of the artificial odor sensing system is to be realized [4]. For this reason, the current research paper aims to survey the interface circuit design for signal conditioning of electronic nose systems. The paper classifies these circuits into two primary categories, which include: integrated circuits (which use very-large-scale integration (VLSI) circuits and sensors both on a chip), and non-integrated circuits (which uses discrete electronic components, such as microcontrollers, field programmable gate arrays (FPGAs), programmable logic devices (PLDs), and operational amplifiers (Op-Amps). At the end, tables are provided to compare frequent methods used and specific application of the e-nose.

The first section of this paper will discuss different types of integrated circuits as proposed by different experts. Besides, there will be a discussion on the different types of technologies employed in developing these circuits. This will provide the reader with a deeper understanding on how these circuits operate with their significance. Section two will discuss the various types of non-integrated circuits. Thereby, it will also help the reader to get a deeper meaning of these circuits. There will also be a discussion on applications of these circuits in this section using a wide range of examples. The last section of the paper will summarize the whole paper in a qualitative analysis format and will include comparison table for these methods and for the application of circuits. Also, the paper ends with a conclusion of the whole study.

II. Integrated Approach

In the paper published by Koickal and colleagues [5], the authors have discussed extensively about VLSI circuit design and implementation of the components of an adaptive neuromorphic odor sensing chip. This integrated circuit system is composed of three systems, which include an on-chip adaptive neuromorphic olfactory model, on-chip sensor interface circuitry, and an on-chip chemosensor array. This system is fabricated on a single chip platform that utilizes the three component functional circuitry constituents. During the 2011 14th International Symposium on Olfaction and Electronic Nose, Aziz et al. [6] presented their findings, where they proposed a different VLSI model that integrates nine separate neuromorphic chips with an aim of creating a comprehensive signal conditioning circuit, which is also capable of solving extremely complex odor sensing problems. The typical circuit arrangement and functionality of the VLSI chip is shown in Fig. 1.

Furthermore, an earlier dissertation presented by Kea-Tiong [7], proposes integrated system capable of applying an interface circuit that is represented as an analogue signal that can be amplified, linearized, offset, altered and compensated for temperature by integrating multiple platform chips. In the circuit design process, the primary approach is to incorporate a power connecting source and field-effect transistors (FET) sensor arrays. This is integrated into a differential circuit used in the processing of signals accelerated from the difference between FET coated array and active FET sensor array. This allows existing common mode signal to be suppressed at the analogue signal input processing unit. At this stage, band-pass filtering is taken into consideration in removing high frequency signal interface and effects related to low frequency drift. Temperature variations introduced by

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electronics, analyze mixture and air passed over sensors are detected by a chip diode at this point [8].

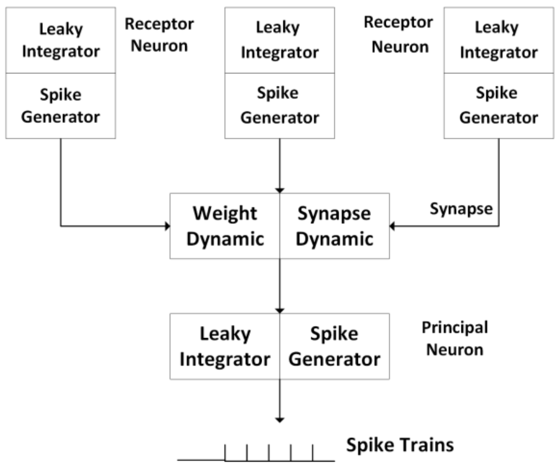

Figure 1: Typical circuit arrangement and functionality of the VLSI chip

On the other hand, the chemosensor arrays consist of diverse sensor types adjusted to react to different biochemical complexes. These heterogeneous arrays have the potential to proliferate selectivity in the artificial olfactory system recognition tasks while imitating the function of the mammalian olfactory structure [9]. The chemosensor array is used as a platform on which olfactory sensors are implemented where carbon black composites are used as a sensing material together with an incorporated signal processing circuit [10]. This sensor interface circuit, as described later, contains a cancellation dc circuit, which ameliorates the loss of measurement ranges linked to array sensors. The signal processing point is formed with spiking neuron design from the olfactory bulb architecture. In addition to this chemosensor array, an on-chip spike-time-reliant conditioning-learning circuitry is incorporated to dynamically familiarize with weights needed in the classification and detection of odors [6].

It is crucial to implement an on-chip learning program in the chemosensor array design, so as to enable the system to sense, recognize, and distinguish odors before passing them into the next sensor interface circuit [7]. Koickal et al. notes that this approach provides a compensation for the VLSI analog imperfections and enables it emulate plasticity function present in biological olfactory systems in line with the environment where the device must operate [5]. In most research works, the chemosensor arrays circuit elaborated above has been successfully fabricated and emulated in silicon [3-6].

In the neuromorphic olfactory chip, the olfactory bulb circuit is fitted with an input that has chemosensors fabricated with a 0.6 μm Austria Micro System. Through chemoresistive arrays, a chemically sensitive film is fitted to measure sensor responses as a factor of change in resistance. Additionally, carbon black coating is used as a polymer material depending on the targeted odor employed in the pattern recognition task. Operatively, the materials work by merging carbon nanospheres with an insulation rubber that provide electrical conductivity to the final resultant mixture. However, individual chemoresistant sensors across the circuit can be achieved by depositing carbon black polymers between any two sensor conductors. Gatet, Tap, and Lescure [11] denote that every sensor along the circuit is usually fitted with a baseline cancellation circuit, sensor, and a source of current. Hsieh & Tang [12] use multiplex mechanisms with an aim of giving access to individual sensing arrays without any complex circuits. Nonetheless, in integrated circuit approach, the problem is creating a sensing array that has individual outputs directly fitted to signal conditioning so that there is a continuous sensor response that is interfaced to neuronal circuits short of complex connections in achieving optimal amplification.

Once the chemosensor array is in place, the next stage is to design the sensor interface circuitry to mimic the neuromorphic model. Chible [9] recommends an active VLSI analogue input to ensure complexity and parameters of the model are quickly mapped to the VLSI environment. An undesirable characteristic associated with a heterogeneous chemosensor array is the large variation in baseline dc signals among the different sensors types in the array. Signal conditioning is aimed at performing a number of critical functions including noise cancelling, temperature compensation, offset control, amplification, linearization, multiplying array output signals, and sensor biasing [4].

According to [5], circuit building is achieved through two approaches: focusing on sensory output and designing an adaptive neuromorphic olfaction chip. First, the neuromorphic olfaction chip is realized by implementing various chip cycles. On sensory approach, the primary challenge in designing circuits is to compensate large differences in baseline sensors in the chemosensor arrays that can result in unrecoverable loss of measurement ranges. This is achieved by implementing a dc cancellation on the chip so to annul variations in baseline sensors. Second, implementation of neuromorphic model is linked to designing a circuit that has large time constraints and at the same time maintaining the neuron structure simple while occupying a limited space in the silicon area [7]. A case by Koickal et al. [5], uses simple operational transconductance amplifier-capacitor (OTA-C) structures to design on-chip learning circuit, synapses and neurons. In addition, the need for large space capacitors can be eliminated through reduction of transconductance on the OTA-C stage in the 300ms range.

III. NON-INTEGRATED APPROACH

A range of different circuit designs used in non-integrated systems applies discrete electronic components, such as microcontrollers, FPGAs, PLDs and Op-Amps. First, in the Op-amp, is well designed to address a number of challenges; variance in baseline resistance, which can be fabricated easily into tens of ohms to infinity ohms when polymer based resistance sensors are used, and the Op-amp also address large coefficient in temperatures in chemosensors which can reach 10(-2) Cº [13]. A signal conditioning approach based on Op-amp can solve this problem as it is based on a principle proposed by Hatfield [14]. Hence this has the capability to remove common mode effects. The approach has been proposed previously by Dyer and Gardner [15], and also reflected in the works by Hatfield and Chueh [16], who instigated for its need to be reserved as a circuit interface in polymer sensor conductors. The circuit is formed by using two identical chemo resistors as shown in Fig. 2, where Ri is passivized with an impervious coating. In this case, the Op-amp circuit can be grouped as an innovative technique of an active divider circuit. The first Op-amp senses the current from the virtual earth and modulated by the passivized chemosensor (Ri), when it is introduced into the sensor. This offsets the baseline voltage present in the Op-amp circuit and this sensitivity can be amplified through a high gain voltage amplifier.

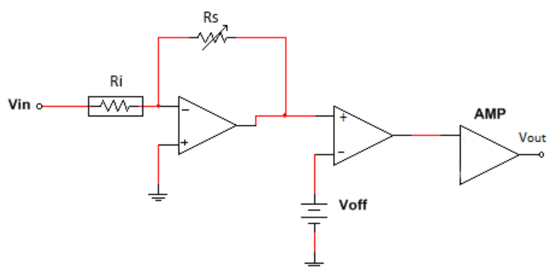

Figure 2: The ratio metric op-amp circuit

The second approach applies the FPGA implementation, where its olfactory circuit is interconnected to multiple non-integrated chipsets. The sensors employ chemo-sensor carbon black with a signal processor circuit. Various scholars, such as Sudalina and Nalini [17], who designed integrated sensor systems, have designed the circuit and technology using spike time linked neuromorphic model to mimic an e-nose system in FPGA. The circuit includes a chemical sensor with a dc cancellation and spiking neuronal network is merged to form a signal processor while the learning platform continuously weighs classification and detection [4].

Tan and Halim [18], based on data acquisition system shown in Fig. 3, have developed another non-integrated technology that runs on the FPGA platform but utilizes metal oxide technology. The technology is applied in identification of sulphate reducing bacteria that causes microbial corrosion in anaerobic environments. The sensor type is composed of an array of semiconductor metal oxides similar to one applied by Zhai et al. [19], an artificial neural network, and a data processing unit. The circuit architecture has two components: one between FPGA and the sensor, and another one between FPGA and the PC (Fig. 4). The first structure consists of the sensing oxide gas, which is designed to detect analog signal outputs so that the data can be processed at the FPGA interface, while the second component uses Quartus II software and Verilog language for learning the odor in the system. Modern approaches that have been developed are aimed at speeding or reducing the period taken to detect the presence of sulphate-reducing bacteria.

Another non-integrated system has been proposed by Tang et al. [20], where a portable e-nose system is built in printed circuit board (PCB) interface with 8 commercially available microprocessors, and a sensor array (Fig. 5.a). Through the circuit, there is a data acquisition card and a display implemented on LabVIEW program for certifying the e-nose system. It is designed to mimic an olfactory system that can test complex fruit odors including litech, banana, and lemon. The interface PCB comprises an 8-bit analog-to-digital converter (ADC), eight to one multiplexer (MUX), and an eight interface processing circuits (IPC). Eight sensors are connected to 8 interface processing units and this adapts actively to the baseline voltage circuit. The IPC operates on two modes; sensing mode and adaption mode. The principle works similar to that developed by Harun, Covington and Gardner [21], where in the adaption mode, the circuit regulates its operational point to a given baseline preset voltage while the sensing mode establishes gate voltage by using a negative loop on the odor passed across the system (Fig. 5.b).

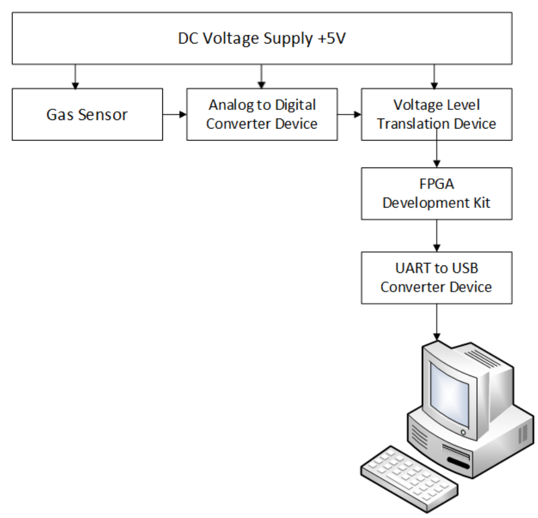

Figure 3: Data acquisition system architecture

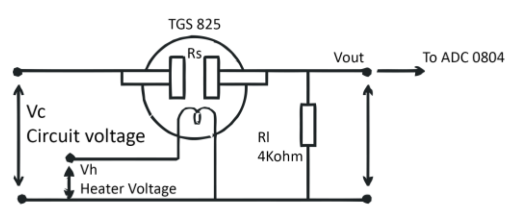

Figure 4: Signal circuit detection interface

Based on Figaro sensor system, Mamat, Samad, and Hannan [22] implemented a technology for implementing and classifying beverages. Their circuit design incorporated temperature sensors and commercially available metal oxide gas sensors. The system uses Principal Component Analysis (PCA) and Multi-Layer Perception Neural Network (MLP) platform and diverse sensor batches to authenticate the model's reproducibility. For the circuit to work, the system requires a simple measuring and heating model. The two are built inside and require a 40 °C, which is realized through a constant voltage supply similar to work by Peris and Gilbert [23]. Here, two voltage inputs operate at 12 V and 5 V circuits (Fig. 6.a & 6.b). Units of 5 V are needed to stabilize the inner sensor circuit unit while the 12 V circuit is required in measuring the output sensor (Fig. 6.c).

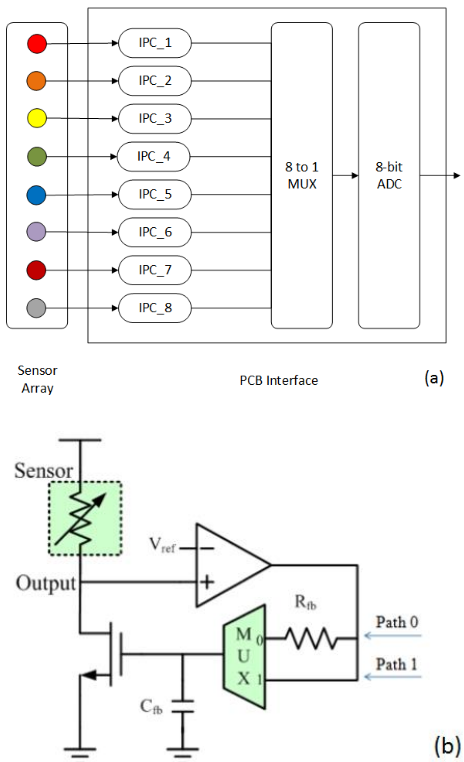

Figure 5: (a) Interface PCB, (b) Basic architecture of the processing circuit

On their part Kim, Yang, Ha, Pyo, and Chang [24] have proposed a miniaturized e-nose system developed using personal digital assistant (PDA) and 8-channel vapor detection array. The technology is based on PCB interface circuit and it is used to successfully classify and distinguish between essential oils including eucalyptus plants, lavender, and mint. The circuit is made up of manually assembled material including processing program, data acquisition, sensor chip array, and test samples. The primary element of the circuit is the 8 channel array chip whose fabrication is achieved by the carbon-black polymer, established in a substrate flexible polyimide. Inside the 8-sensor chip, there is a voltage divider system that weights large standard voltage (Fig. 7). The system is applied in sensing a wide array of fruit odors such as oranges, mangoes, and black-current.

Furthermore, Chiu, Tang, Chang, and Hsieh [25] have proposed a low power signal sensor technology based on a multi-walled nanotubes (MWNTs) circuitry interface, which is a polymer that swells reversibly upon exposure to chemicals. At low power, the sensor technology is formulated to identify 2-Butanone, chloroform, and carbon tetrachloride. The circuit chip is based on microprocessor embedded on pattern sensing algorithm, digital-analog converter, and interface circuit (Fig. 8). The adaptive interface circuitry has a sensing mode and an adaptive mode and the system works like the one proposed by Mamat, Samad, and Hannan [22] as previously discussed.

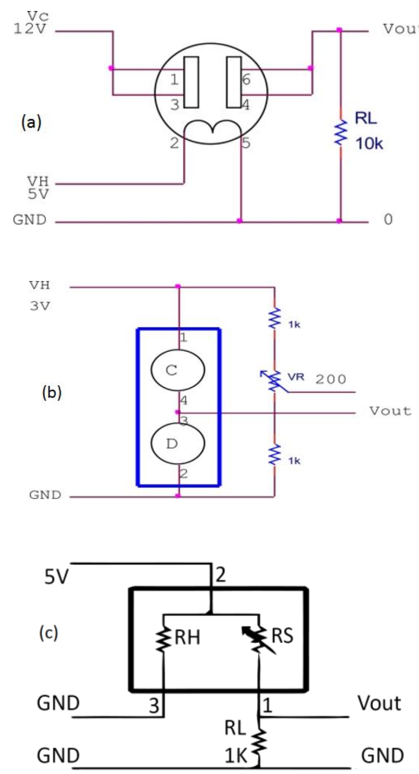

Figure 6: Interface circuits for (a) TGS8xx sensor, (b) TGS2xxx sensor, and (c) TGS6812 sensor

Another low power identifier system has been proposed by Young et al. [26] to form an intelligent wireless e-nose network (WENN) based on microcontroller interface. The interface is designed to incorporate two sections: first, there is a saturator that mixes with the target gas before releasing to the testing chamber; two, the WENN measures periodical gas entry from a thermal modulated microarray and neuronal-fuzzy network. The WENN system is designed to identify two binary gases, which are H_2S and NH_3.

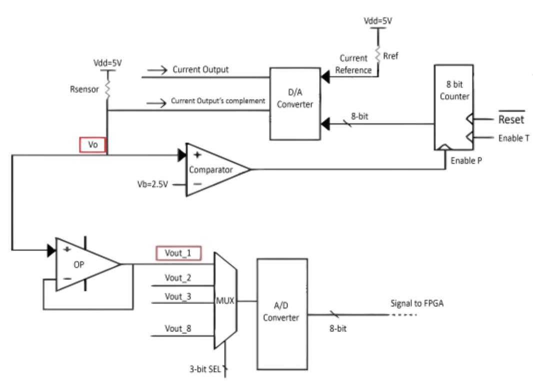

Figure 7: PDA-based E-Nose system interface circuit

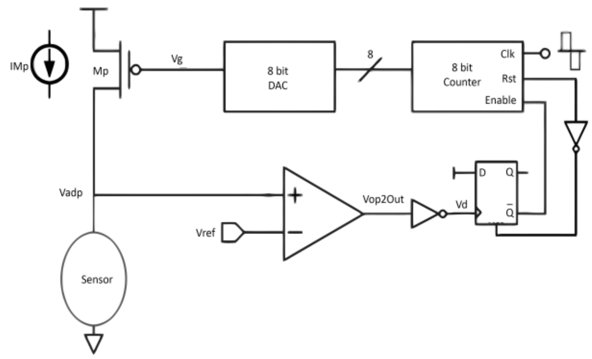

Figure 8: Adaptive interface circuit in Low power e-nose chip

In micro-electromechanical field, Stavrov et al. [27] have proposed a piezoresistive sensor technology centered on fast signal processing and parallel operation. The system is based on microcontroller circuit and mostly that of a silicon cantilever and Wheatstone bridge. The length of the cantilever is designed to avoid mechanical cross talk and to simplify resonance frequency. The system also incorporates 4 input/output (I/O) to operate by deflecting self-sensing and in supplying power. It measures a resonance spectrum in mechanical checkups applied in e-nose during the identification and characterization of various analytes. This device can be produced from manufacturing technology, basing on micro-mechanical cantilevers. In such a case, it relies on the ability to implement a parallel operation and a faster signal processing.

IV. Discussion

Table I gives a comparative summary of technological sensors largely used, their applications, and their interface circuit and research references. From the above analysis, about sensor types and their application it is clear that interface circuitry is a very important factor in achieving an appropriate technology and circuit olfactory sensor sensitivity. Most sensitivity circuits used in inorganic sensors employ microcontrollers, while organic sensors are largely used in organic olfactory systems. Even if the circuit sensitivities may be elevated with amplification, this improvement may be marginal because of the baseline voltage component in the signal amplification. On circuit interface and sensitivity application best circuit performance is achieved by eliminating sensor baseline voltage.

The circuits discussed above use the simplest technique of counteracting the baseline voltage through its second potential divider. As deliberated previously, a signal conditioning circuit that has a linear productivity characteristic imparts itself to the role of odor classification and analysis. Therefore, it may seem from the analyzed circuits that the most suitable presentation, in terms of linearity and sensitivity is ratio metric op-amp and the constant current resistance interrogation circuits. The Op-amp circuit interface has a large advantage of excluding the temperature effect from the baseline output signals through the application of a passivized active sensor copies.

Table I: Different technological sensors, their application and type of interface circuitry used

Technology/Sensor type	Application	Interface Circuitry	Reference
1. Data acquisition system	Sulphate reducing bacteria	FPGA	[18]
2. Portable e-nose	Complex fruit odors e.g. lemon, banana, litech	Interface PCB (printed circuit board)	[20]
3. Figaro sensor-Measurement and Classification	Fruit sensor-black current, mango, orange	Microcontrollers PCA, and MLP	[22]
4. Miniaturized e-nose	Classification of essential oils eucalyptus, lavender, mint.	PCB	[24]
5. Low power e-nose chip	Sensing 2-butanone, chloroform, carbon tetrachloride	MWNTs	[25]
6. Intelligent wireless e-nose (WENN)	Binary gas mixtures H2s, NH3	Microcontrollers	[26]
7. Piezoresistive sensors	Micro-electro-mechanical system	Microcontroller/ Wheatstone brdge	[27]
8. Frontal-end signal	Odor sensing	Ratio-metric Op-amp	[28]
9. Analog circuit design	Odor classification and detection	Analog VLSI	[5]

It can be established that, among the signal-conditioning circuits examined, Op-amp circuits address majority of the issues that have been defined previously.

V. Conclusion

Individual e-nose performance relies on its performance and effectiveness and its constituent interface circuit. This survey paper has looked into various sensor technologies, their application and circuitry interfaces they use. It is clear that careful selection and design of frontal nose signals at the posterior of the conditioning circuit is of critical significance if optimum performance of the artificial odor sensing system is to be realized. However, most cases we have presented are proposals in theoretical works and studies that need to be developed further to determine their application in real-time odor sensing. Future technological aspects should address various challenges that are expected in the ultimate integration of a complete structure. This will require careful deposition of sensor material with wide diversity of chemical sensors that are needed together with screen process for every sensor, so as to ensure there is ideal chemical response recognition. Systems and circuit issues, such as the use of address event representation or spike output, layout optimization, component mismatch, and lasting weight storage also should be addressed.

Most examples for integrated circuits presented in this paper have differential circuits with ability to process signals accelerated from the difference between FET coated array and active FET sensor array. Thus, allowing existing common mode signal to be suppressed at the analogue signal input-processing unit. On the other hand, most non-integrated circuits presented here have temperature sensors and commercially available metal oxide gas sensors. As evidenced from this paper, non-integrated circuits are characterized by change in resistance and low power consumption. From various findings in this paper, most of these circuits rely on Principal Component Analysis and Multi-Layer Perception Neural Network platforms and have diverse sensor batches for their systems authentication. Hence, this new technology is reliable for commercial purposes.

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