An artificial neural emulator for an odour sensor array

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Abstract

In this paper we describe the development of a stand-alone microprocessor-based instrument which can classify intelligently the signals from an array of odour-sensitive sensors. Data from the odour sensor array are initially used to train a neural net on a PC using a software program and then sent down an RS-232C interface to the artificial neural emulator (ANE). The ANE uses multiplexer and ADC chips to condition the array output, followed by a Motorola 6803-based digital processing stage that contains in its RAM or ROM, an artificial neural architecture, neuronal weights and an operating instruction set. The processor computes the output of a neural network, classifies this against a knowledge base of odours and displays the result on a two-line LCD display. The ANE has also been fused with an array of four commercial gas sensors (Figaro Engineering Inc., Japan), a temperature IC and a capacitive humidity sensor to produce a stand-alone intelligent odour-sensing system.

1. Introduction

Considerable effort is being directed towards the development of an artificial odour-sensing instrument or so-called electronic nose [1]. These instruments basically consist of an array of chemical sensors with partial selectivities and an appropriate data processing technique. A variety of sensor technologies have been exploited in odour sensors, such as metal oxide chemoresistors [2], lipid-coated quartz resonators [3] and polymeric chemoresistors [4]. Conventional chemometric techniques have been applied to the analysis of such data [5]. However, recent interest has been in the use of artificial neural networking techniques (ANNs). There have been consistently good reports of the application of a backpropagation algorithm [6] to all these sensor technologies [7–9]. These results were obtained using a microcomputer-based system with a separate sensor array, analogue interface circuit and microcomputer (e.g., IBM PC). It is highly desirable to have a stand-alone portable instrument rather than a discrete microcomputer-based system. First, the instrument would become portable so that it could be used in remote areas, perhaps battery powered. Second, the instrument would have a lower cost than a PC-based system; lastly, under microprocessor control it could have self-diagnostic facilities, and when necessary be recalibrated via a digital interface. We have developed such a neural network tool which we call an artificial neural emulator (ANE) using low-cost commercial sensors and microelectronic components [10]. Current neural tools fall into one of three categories: software simulators for use on a PC or workstation platform, mixed software and hardware simulators (e.g., an accelerator board), and hardware implementations, such as WISARD. The ANE is of the second type but provides a much lower cost and ease of use than, for example, a transputer-based and DSP-based system.

2. Odour sensor array

The development of the ANE has been carried out in two stages, see Fig. 1. In the first stage we developed an odour sensor array unit and the ANE separately. The reason for this was that we wanted to make the ANE generic so that it could be applied to any sensor array system and to test the two systems independently. In the second stage we have combined these two units into a single portable instrument for odour-sensing applications.

The odour sensor array unit consists of six sensors: a set of four series-8 Taguchi gas sensors (Figaro Engineering Inc., Japan), a temperature IC (−50 °C to +150 °C) and a capacitive humidity sensor (10–90% r.h.). The odour is drawn across the sensor chamber by an Edwards mini-pump at a flow rate that purges the chamber in about 20 s. Suitable analogue signal conditioning circuits have been built on custom PCBs to produce an analogue output (0–5 V d.c.) via a 15-way D-connector to the ANE or an analogue to digital converter in a PC. A prototype instrument was taken to Iceland and used to measure the freshness of fish under various conditions [11].

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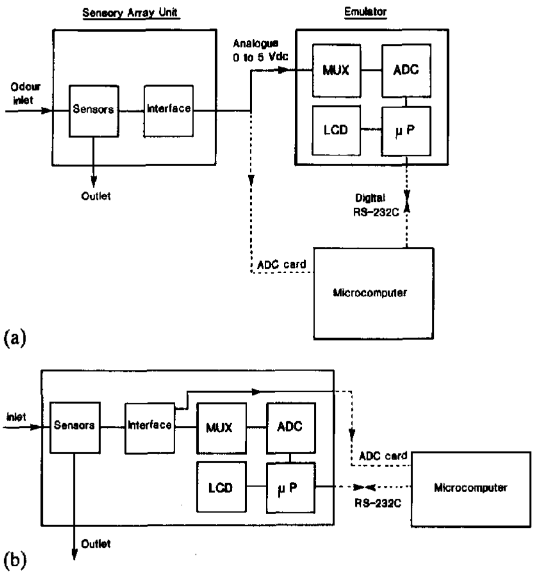


Fig. 1. Basic configuration of the instrumentation. (a) Separate electronic nose interface and artificial neural emulator (ANE) units. (b) A portable artificial neural emulator-based electronic nose (PANEEN).

3. Artificial neural emulator

The sensor array data are first processed on a PC (AT or XT) using a program written in C that incorporates a multi-layer perceptron model designed by the user. There are three training algorithms available, the standard (fully connected) backpropagation technique that has been successfully used before, and two versions of a genetic algorithm. In the standard backpropagation, the network architecture must be determined manually by trial and error. In contrast, one genetic algorithm optimizes the number of nodes in the network while the other optimizes the number of connections automatically. Figure 2 shows a typical fully connected three-layer backpropagation network that has been used to learn data gathered from an array of odour sensors. This simple configuration mimics the biological olfactory system where the input layer, hidden layer and output layers are equivalent to the olfactory cells, glomeruli nodes and mitral cells [1]. In reality, a more accurate representation would be a partly connected five-layer model but its generalization tends to be poorer.

The ANN knowledge, consisting of the optimized ANN topology, is the key to the operation of the ANE. As such there are basically two ways in which the information can be loaded. The ANN knowledge and appropriate software is either blown into EPROM and installed in the ANE or downloaded via an RS-232C link into RAM in the ANE. The second option is advantageous because we may wish to calibrate the system on a fairly regular basis. Under software control, the analogue voltage signals from the sensor array are processed by a 4067B multiplexer and ZN448 8-bit successive approximation ADC and then presented to the neural network for classification. The process is controlled by control keys on the front of the instrument case and information is displayed by a 16-character two-line LCD dot matrix display. Figure 3 shows the layout of the ICs in the ANE microboard [12]. The hardware is capable of processing a network of several hundred processing elements (max. 16 nodes in the input layer). The unit has been re-engineered by Neural Technologies (UK) to produce a generic ANE, known as the NT5,000 which can process signals from any sensor system, in principle.

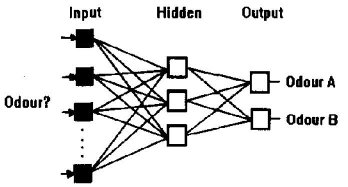


Fig. 2. The standard three-layer back-propagation neural network commonly used to train electronic nose data.

4. A portable artificial neural emulator-based electronic nose (PANEEN)

In stage two of this work, the odour-sensing array and the ANE have been combined in a single stand-alone portable instrument as shown in Fig. 4. This has the advantage of reducing the size and cost through the use of a common power supply, enclosure, etc. The ANN design and installation works in essentially the same manner as described previously, namely that odour data is captured by the PC and used to train the ANN. Then the ANN knowledge is used with the integral ANE, either via RAM or EPROM to control the operation of the PANEEN. Thus after sampling the odour for about 60 s, the unit classifies the odour in much less than a second and displays the results on the LCD.

5. Future work

At present the training of the neural network is performed on a PC or workstation using C-code. This provides the advantages of a flexible and easy-to-use design station as well as lower training times from the faster processor. However, recent developments are leading to superior neural paradigms that train much

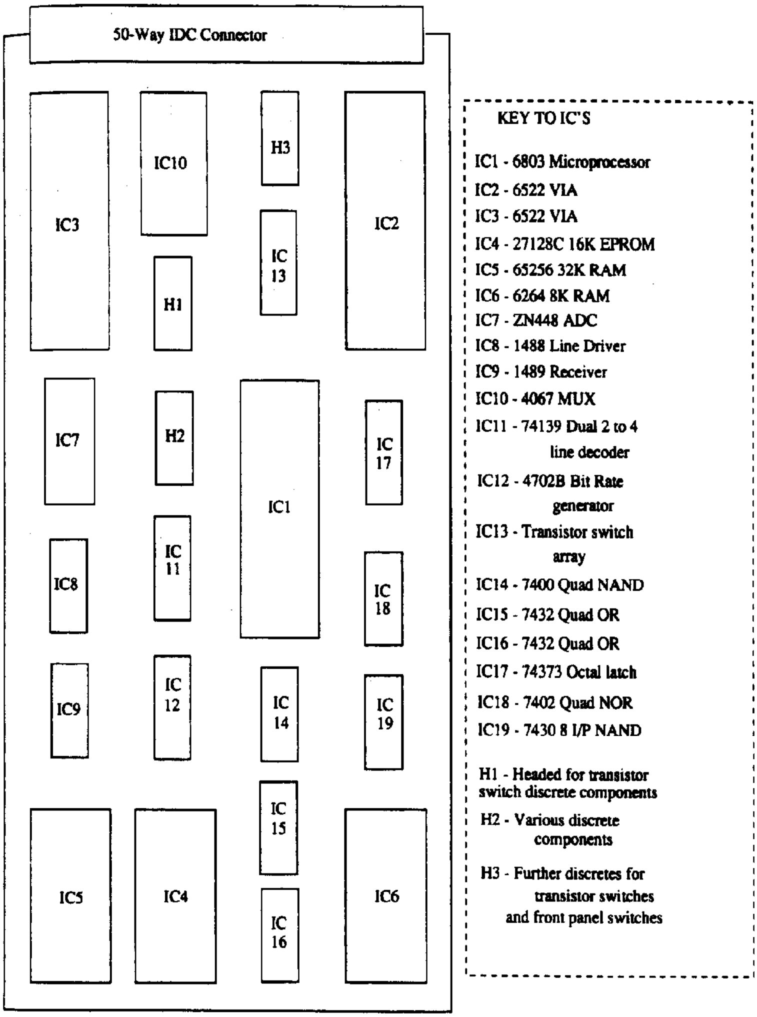
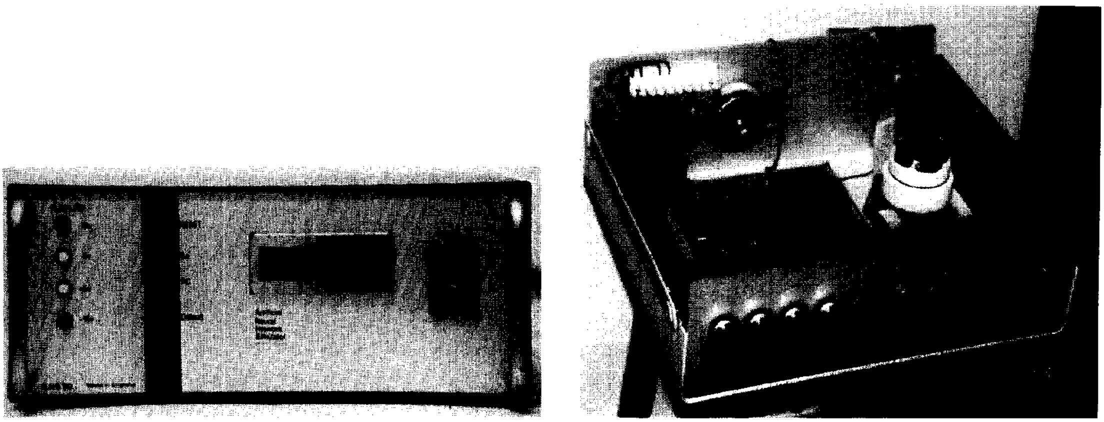


Fig. 3. Layout and choice of the ICs on the ANE motherboard.



(a) (b)

Fig. 4. Photograph of the intelligent instrumentation. (a) ANE. (b) PANEEN.

more efficiently and so it should be possible to provide realistic on-board training in the near future. This is a practical proposition when there are a relatively small number of sensors to process (e.g., less than 20). The flexible design of the PANEEN also permits the implementation of superior signal processing algorithms, e.g., to include automatic temperature or humidity compensation. Lastly, our modular approach to the PANEEN design facilitates the replacement of the discrete commercial metal oxide gas sensors with other types, such as an integrated conducting polymer array sensor.

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