Stereo-olfaction with a sniffing neuromorphic robot using spiking neurons

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SUMMARY

This paper presents a neuromorphic robot using stereo-olfaction and a sniffing system based on nonselective chemosensors that mimic the animal behavior of tracking a specific odor. In order to be able to go toward an odor source, two tasks must be performed : 1) estimation of the gas-concentration gradient and 2) gas recognition independent of the intensity. It is shown how these two tasks can be implemented with artificial spiking neurons in a biologically inspired approach.

Keywords: electronic nose, stereo-olfaction, spiking neurons, gas localization, autonomous robot.

Subject category: 10.

INTRODUCTION

The detection and localization of drugs, explosives or gas leaks in hostile environments or in public places is currently a very active area of research. Because animals like dogs have the ability to track odors, there have been several attempts at developing biologically inspired robots capable of searching for a specific odor source. For example, the robotic 'lobster' in [2] was designed to track saline plumes in water, and the odor compass in [6] was based on the behavior of the silkworm moth. These approaches have shown encouraging results in the presence of a single gas and a sensor selective to that gas. It is well known however that chemosensors are highly nonselective and respond to a wide variety of gases, as do the broadly tuned olfactory receptors in mammals. Unlike previous work, we therefore consider in this paper the task of tracking a specific gas with nonselective chemosensors. In order to have such a behavior, two tasks must be performed: 1) estimation of the gas concentration gradient and 2) gas recognition independent of its intensity. Tasks 1 and 2 are implemented by using stereo-olfaction and synchronization of spiking neurons, respectively.

The use of stereo-olfaction is supported by observations in humans and honeybees which indicate that a small difference of 10% in concentrations between the two olfactory sensors (nostrils or antennas) is enough to estimate the gas-concentration gradient [5]. Although the mechanisms of chemotaxis in animals are not exactly known, many animals may use an estimate of the gas concentration gradient by comparing the responses between the two sensors. This is likely to happen when the two sensors are widely separated, as in hammerhead sharks for example.

The use of spiking neurons is motivated by recent studies showing that the synchronization of spikes of relay neurons in the first stage of the olfactory system may play an important role in odor recognition [4,8]. In another context, Hopfield [3] proposed a biologically plausible time advance encoding scheme capable of recognizing an odor independent of its intensity by synchronization of spikes.

HARDWARE CONSIDERATIONS

As shown in Figure 1, our olfactory system is situated on a mobile robot with an onboard computer and two sensor arrays. To mimic sniffing stereo-olfaction, the two arrays are placed on either side of the robot. This allows us to obtain an instantaneous estimate of the gas concentration gradient through a differential measurement. A closed plexiglass chamber encompasses each sensor array. In order to limit turbulence effects due to the movement of the robot, an inlet pipe allows it to sample the surrounding atmosphere in front of the robot. A pump then feeds the gas directly to the sensors. Each sensor array is composed of ten TGS Figaro gas sensors divided into five different types.

The gas sensors commercially available present a lack of selectivity. The idea to combine the responses of individual sensors to improve selectivity to a particular odor is not new, and can be traced back to 1982 [7]. This approach emphasizes some similarities with mammalian olfaction and therefore such systems are often named electronic noses in analogy with their biological counterparts.

ALGORITHMIC CONSIDERATIONS

It has been shown that the steady state ratio x_{ij} of the resistance in gas to that in air of a TGS sensor i varies in a non-linear way (power law) with gas concentration C_j. For high concentrations, we can consider the following law

$$x_{ij} = \alpha_{ij} (C_j)^{r_{ij}} \qquad (1)$$

where α_{ij} and r_{ij} are coefficients that depend upon the sensor and the gas.

Let us consider now the following situation: we are in presence of a gas k and we want to recognize a gas j. If a sniff occurs at time t = 0 we consider, for the input neuron i whose entry comes from sensor i, its first spike time t_{ik} to be given by

$$t_{ik} = (\log x_{ik})/ r_{ij} \qquad (2)$$

where x_{ik} is the steady state ratio of the sensor resistances. This spike will arrive at the output neuron after a delay Δ_{ij} given by

$$\Delta_{ij} = \Delta_j - (\log \alpha_{ij})/ r_{ij} \qquad (3)$$

where Δ_j is given by $\Delta_j = \max (\log \alpha_{ij})/r_{ij}$ in order to preserve causality. If the gas k corresponds to the gas j that we want to detect then, according to eq. 1, the spike arrives at the output neuron at a time $t'_{ij} = t_{ij} + \Delta_{ij} = \Delta_j + \log(C_j)$ which is independent of the neuron i due to the delay. In presence of gas j, all the spikes fired by the input neurons will arrive at the same time. In presence of another gas k, the spikes will arrive at times $t'_{ik} = t_{ik}+\Delta_{ij}$ that are all different. Therefore, given a suitable set of synaptic delays, spike synchronization will occur in the presence of gas j only and for any concentration of the gas (task 2).

We have used two spiking neural networks (left and right), one for each sensor array. Each network implements the pattern recognition system described above using spiking neurons similar to integrate and fire neurons. Indeed, the logarithmic encoding scheme used in eq. (2) can be obtained with integrate and fire neurons and an underlying background oscillation [3] and synchronization can be detected by a single integrate and fire output neuron acting as a coincidence detector. The output neuron of each network will therefore be silent if the gas does not match the set of delays but will fire whenever the gas is recognized. Since the firing time at the output is an increasing function of the gas concentration, a behavioral decision towards the side where the concentration is the highest can be made (task 1).

EXPERIMENTAL RESULTS

In the intensity-invariant gas recognition procedure described in the previous section, the set of delays represents a prototype pattern of the gas to be detected. A match between this prototype pattern and the current gas leads to spike synchronization and thus recognition. These delays have been obtained using eq. 3 by fitting the parameters α_{ij} and r_{ij} in the power law model (eq. 1) for the steady state sensor responses in presence of gases with controlled concentrations. We have tested our two sensor arrays with ethanol and butanol vapors for concentrations ranging from 1000 to 3000 ppm at a room temperature of 23°C. An automated gas delivery experimental setup was developed for extracting gases at given concentrations from liquids (Figure 2). It consists of two micropumps, two mass flow controllers, one glass reagant bottle and a data acquisition system. Figure 3 and 4 shows, for the 10 sensors of one array, the steady state ratio of the resistance in gas to that in air with respect to the concentrations of butanol and ethanol, respectively. In each plot, the curve representing the power law obtained with the fitted parameters α_{ij} and r_{ij} is also shown. A perfect recognition of ethanol and butanol has been obtained at various concentrations. Figure 5 shows two examples in which a quasi-synchronization of the spikes is obtained for butanol but not for ethanol.

CONCLUSION

In this paper, a neuromorphic robot using stereo-olfaction and a sniffing system based on nonselective sensors is developed for tracking a specific gas. We have shown that a biologically inspired approach using artificial spiking neurons allows us to 1) estimate the gas-concentration gradient and 2) recognize a particular gas independent of its intensity. This system has been implemented on an autonomous robot and is currently being tested on real gases.

In the intensity-invariant gas recognition described in this paper, the set of synaptic delays represents a prototype pattern of the gas to be detected. A match between this prototype pattern and the current gas leads to spike synchronization and thus recognition. For now, these delays are adjusted by hand using eq. 3 and assuming a power law model for the steady state sensor responses. Because this model is an approximation that may not correspond exactly to reality, future work will focus on learning rules capable of adapting the synaptic delays.

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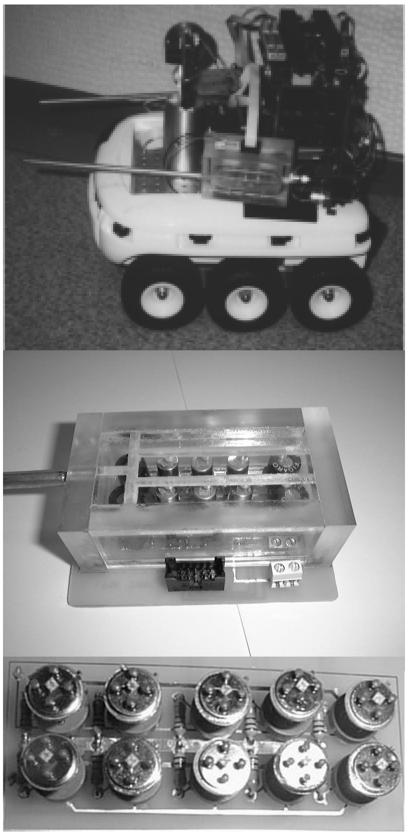

Figure 1. The experimental robotic setup

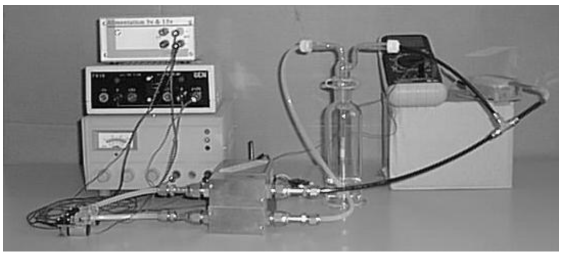

Figure 2. The automated gas delivery system

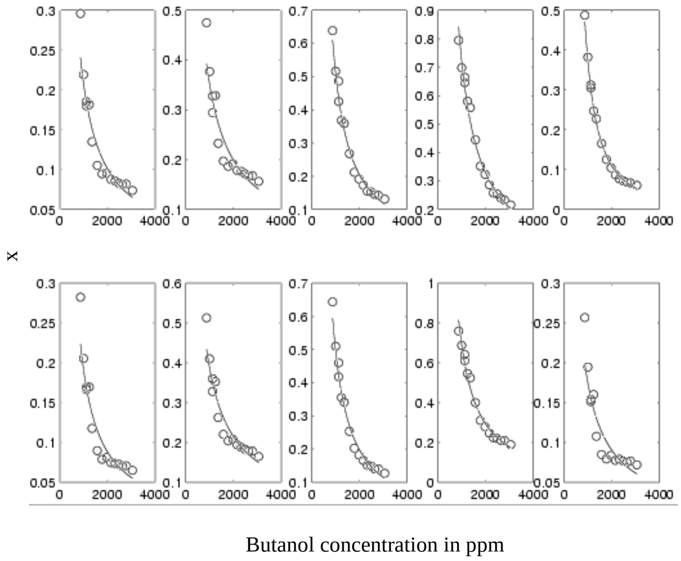

Figure 3. Steady state ratio of the sensor resistances for an array with respect to the butanol concentration (ppm)

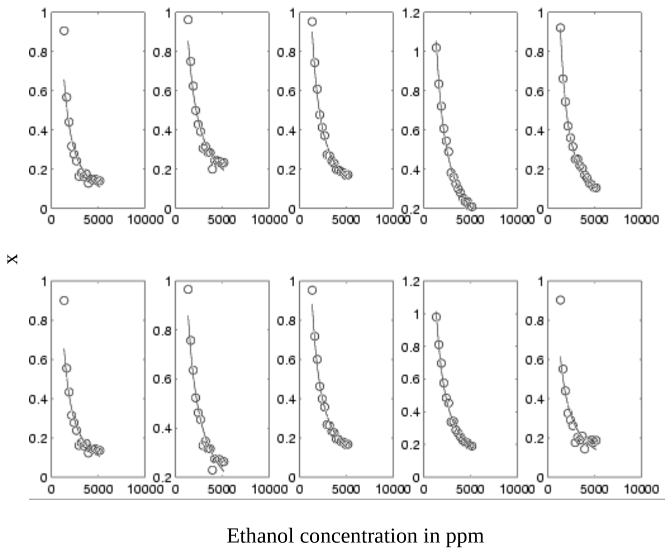

Figure 4. Steady state ratio of the sensor resistances for an array with respect to the ethanol concentration (ppm)

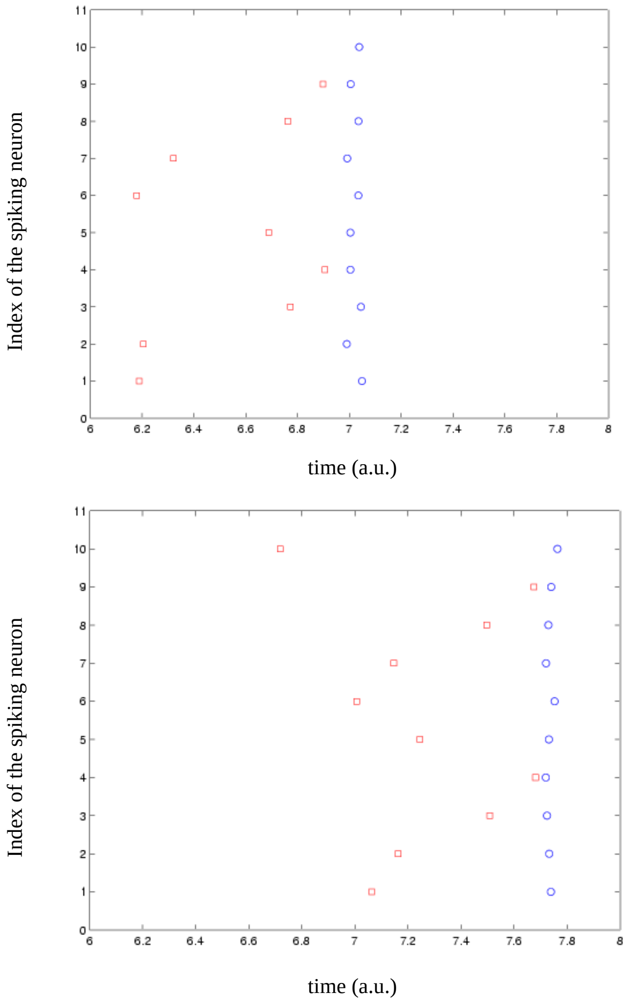

Figure 5. firing times of the spiking neurons for butanol (blue circles) and ethanol (red squares). The concentration is lower for the Figure at the top than for the one at the bottom.