A Stereo Electronic Nose for a Mobile Inspection Robot

Achim Lilienthal[1], Tom Duckett[2]

[1] University of Tübingen, WSI, D-72076 Tübingen, Germany, lilien@informatik.uni-tuebingen.de

[2] Department of Technology, AASS, Örebro University, S-70182 Örebro, Sweden, tdt@tech.oru.se

1 Introduction

Automatic sensing of gas distributions could be very useful for a number of industrial applications. However, while individual gas sensors can be relatively cheap, they can only cover a small area. To cover larger scale environments such as warehouses and factories with a fixed installation of sensors, an arbitrarily large number of sensors would be required, resulting in very high set-up costs. As an alternative solution, the design of an electronic nose is presented (the "Mark III Mobile Nose") that can be used on mobile robots.

One possible application of this mobile nose would be an "electronic watchman" that can detect, localise and identify odours caused by leaking solvents, hazardous gases, fires, etc. However, before such an application can be realized, there are a number of practical problems that must be addressed. For example, the metal oxide sensors used in this research are subject to a long response time and an even longer recovery time. Also, the spread of gases in typical indoor environments tends to be dominated by turbulence rather than diffusion, resulting in very noisy and unpredictable sensor signals. These effects could be lessened by temporal averaging in a static sensor system, but must be minimised by some other method if a mobile system is to cover the environment at reasonable speed.

A mobile nose was developed to solve these problems on a K-team Koala robot (Fig. 1(a)) according to the following design decisions. First, it was decided to use metal oxide sensors with a direct measurement of resistance to obtain the required sensor values, in order to minimize costs. Second, due to the non-directional nature of odour measurements, a stereo nose architecture with two tubes or "nostrils" was used (Fig. 1(b)) to measure the spatial gradient of the gas concentration. This is the simplest architecture that can be used to measure the *instantaneous* gradient of the odour without requiring path integration, as with a single sensor. Third, to reduce the latency of the sensors, suction fans were mounted inside the tubes. Our experiments showed that this design significantly reduced the recovery time of the sensors. Fourth, our experiments also showed that a further increase in performance could be obtained by separating the two tubes with a "septum" or dividing wall to reduce interference between the opposing airflows.

2 Setup of the Mark III Mobile Nose

The Mark III mobile nose consists of six metal oxide gas sensors, which were placed symmetrically in sets of three inside two separate tubes containing a suction fan each. On both sides, metal oxide sensors of type TGS2600, TGS2610 and TGS2620 were used. The distance between the two sets of sensors was 40 cm. Papst Fans (405F) were used that generate an airflow of 8 m^3/h. The sensor arrays were mounted at the outer end of the tubes in order to maximise the instantaneously measurable spatial gradient (see Fig. 1(a),(b)).

3 Dynamic Response

In order to determine the dynamic response of the Mark III mobile nose *as a whole*, the following experiment was performed: alternately one set of sensors was exposed to a step stimulus, which was approximated by opening a bottle of ethanol in the direct vicinity of the sensors for a fixed period of time. For each of the 4 possible configurations that result from using or not using the fans and separating or not separating the two tubes with a septum, the following steps were repeated:

- wait for 20 s,
- open a bottle of ethanol for 10 s at a distance of $\approx$ 1 cm in front of the sensors on the chosen side,
- close the bottle and wait for another 120 s.

The readings were analysed by fitting a sensor model to the values recorded during each trial. Due to the complexity of the interaction between metal oxide sensors and their environment, no physically justified general description of this process is available. It is, however, sufficient for our concerns to assume an ideal first-order sensor and thus model the dynamic response to a step stimulus as an exponential rise and decay. To this end, the applied model separates into three parts according to the three regions shown in Fig. 1(c). The model contains 7 adjustable parameters: the response level before (R_0) and after (R_0') the stimulus, the saturation level (R_{max}), the time constants of rise (τ_r) and decay (τ_d), the time before the sensor started to respond (t_S), and the

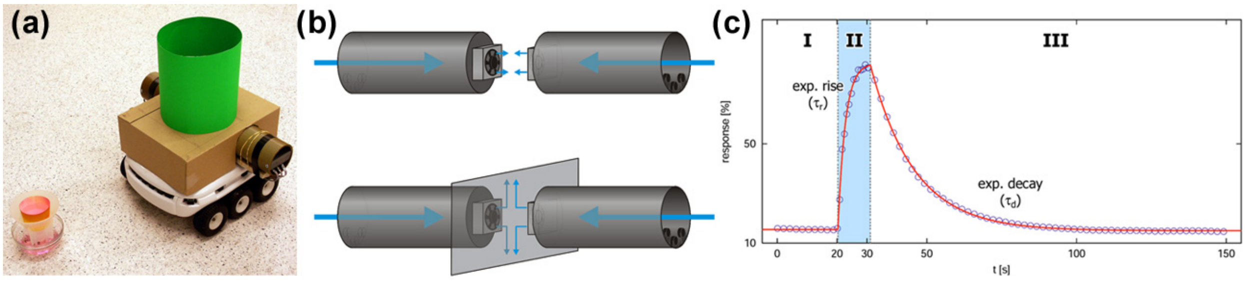

Figure 1: (a) The Mark III Mobile Nose mounted on a Koala robot, (b) schematic view of the nose with and without a septum, and (c) first-order sensor model fitted to real sensor data.

duration of the rising period (Δt). To determine these parameters, the model was fitted to 600 data points recorded per trial using the Marquardt-Levenberg algorithm [5].

The average value of the time constants of rise $\overline{\tau_r}$ and decay $\overline{\tau_d}$ are given in Table 1, calculated for one pair of sensors (TGS2620), from those trials where the stimulus was on the same side as the corresponding sensor.

Config.	$\overline{\tau_r}$ [s]	$\overline{\tau_d}$ [s]
NF&NS	1.93±1.18	28.88±6.02
F&NS	1.85±0.71	10.20±0.75
F&S	1.91±0.96	9.90±2.14

Table 1: Fitting results of the dynamic sensor response to a step stimulus for a configuration with fans (F) or without fans (NF), and with septum (S) or without a septum (NS).

The fitting results showed that the assumed model is able to reproduce the actual response of the mobile nose quite well. Furthermore, no significant difference in the rising time constant $\overline{\tau_r}$ could be found whether fans were used or not. By contrast, the decay time constant $\overline{\tau_d}$ turns out to be significantly higher in the case where no fans were used.

A reasonable estimate of the sensor response is provided by the mean values of the time constants (averaged over all six sensors):

$$\tau_r \approx 1.8s \qquad (1)$$

$$\tau_d^{(NoFans)} \approx 20.7s \qquad \tau_d^{(Fans)} \approx 11.1s \qquad (2)$$

Note that the rise and decay constants depend generally on the sensor type. In addition, these characteristics vary between different sensors of the same type, and also for one sensor over prolonged periods of time. Finally, they also depend on the gas concentration. Bearing these restrictions in mind, the approximation given in (1) and (2) provides a reasonable notion of the mobile nose's characteristics: the use of fans does not influence the response time to a presented stimulus, but rather lowers the time needed for the sensors to recover after the stimulus has been removed. This is caused by the higher rate of air exchange effected by the fans.

An increased exchange of gas provokes, on the other hand, a less clear distinction of the measured response due to an increased exchange of gas between the opposite tubes. Our results indicate that this disadvantage can be counterbalanced by separating the tubes with a septum.

4 Conclusions

The statistical analysis of the experiments provided an estimate of the exponential time constants of rise and decay of the Mark III mobile nose. While the metal oxide gas sensors respond fairly quickly to an increased concentration, they recover much more slowly, resulting in a considerable integration of successive measurements (see (1),(2)).

The time constant of rise is almost unaffected no matter whether fans were used or not. By contrast, the time constant of decay is almost half as long if fans were used, indicating that it is favourable to use fans in order to get measurements that reflect the instantaneously sensed concentration as closely as possible. On the other hand, the airstream produced by the fans must then be separated carefully, for example, by using a septum or dividing wall.

The Mark III mobile nose has been utilised successfully in a number of experiments, including reactive gas source localization with a smelling Braitenberg vehicle [3], localization by concentration peak avoidance [1], and gas distribution mapping [4, 2].

References

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