

# LEAKAGE LOCALISATION WITH A MOBILE ROBOT CARRYING CHEMICAL SENSORS

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## ABSTRACT:

On the way to an electronic watchman one more sense, i.e. gas sensing facilities are added to an autonomous mobile robot. For the gas detection up to eight metal oxides sensors are operated using a commercial sensor system. The robot is able to move and navigate autonomously. The geometric information is extracted from laser range finder data. This input is used to build up an internal map while driving.

Using the new sense the localisation of a gas source in unventilated in-house environments is performed. First experiments in a one-dimensional case show a very good correlation between the peak and the gas source. The one-dimensional concentration profile is repeatedly recorded and stable for at least two hours. The two-dimensional experiments exhibit a circulation of the air within the room due to temperature and hence density effects. The latter is limiting the available recording time for the two-dimensional mapping.

## 1 INTRODUCTION

There is an increasing demand for chemical analysis instrumentation to inspect chemical warehouses and industrial production sites for leakages of hazardous chemicals. Autonomous operation in the vicinity of hazardous material with remote supervision is a requirement for the safety of human operators. To achieve these objectives, a prototype robot equipped with multi-sensing facilities was used. The mobile robot features stereo optical sensing, ultrasonic and laser distance recognition, and a chemical sensor system allowing unsupervised movement in a given environment. The robot is able to imitate an electronic watchman localising leaks and detecting a source of contamination.

## 2 STATE OF THE ART

Various groups showed before measurements with gas sensor systems mounted on mobile robots. One goal was to use an odour trace to find the way back to the starting point or to guide other following robots<sup>(1, 2, 3, 4)</sup>. There, the localisation of odour sources was demonstrated in special environments: constant airflows and the use of huge sources with special odours<sup>(5, 6)</sup>. This constant airflow, for example in clean rooms, is an immense advantage while locating gas sources. The gas source generates a plume, with a well-defined concentration profile and it is stable in time. In this case an upwind search can be performed by driving across the plume. The airflow used by other authors is in the range of 30 to 50cm/s and can be measured easily. In contrast, the normal thermal convection below 5cm/s is difficult to quantify.

In the given case study no air stream is used hence the upstream search across plumes cannot be applied. The authors are actually interested to perform a concentration mapping first, in order to elaborate sub sequentially intelligent search strategies.

## 3 EXPERIMENTAL

### 3.1 Sensor System

In the work presented here, a commercial sensor system VOCmeter-Vario (Applied Sensor AB, former MoTech<sup>7</sup>, *Figure 1*) was mounted on a robot (ARTHUR, RWII<sup>8</sup>, *Figure 2*). The system allows connecting up to eight sensors to the main unit by using special connectors (sticks). These sticks are available for metal oxide sensors (MOX), 30MHz quartz micro balances (QMB), and as a general input module.



Figure 1: VOCmeter-Vario with two sensor sticks connected via a RG 158 coax cable. It is possible to connect up to eight different sensors. All sensors are driven by the electronics in the main unit. The sensor signals are transmitted to a computer via a serial RS-232 link.

The sensor-sticks are connected to the base unit with a thin flexible RG158 coax cable. The base unit measures up to 4 times per second every eight connected sticks and transmit the values via a serial RS-232 link to the computer inside the robot.

QMBs are not sensitive enough for very low concentrations of usual solvents. When using QMBs large odour sources and molecules with a high mass, like camphor, are required. In contrast to the examples mentioned above, the authors aimed at the detection of usual solvents in low concentrations. Accordingly, high sensitive metal oxide gas sensors were used. Ethanol and acetone were used as solvents, which are non-toxic, and give large sensor signals.

The eight sensors (TGS 2620 Figaro<sup>(9)</sup>) were calibrated with a gas mixing station, imitating the same conditions as in the real experiment in order to estimate the concentrations of the measured signals. Various conditions were changed: The mounting direction of the sensor to the airflow, the total airflow and the humidity. The first two parameters have very small influence to the signal; increasing humidity increases the signal slightly.

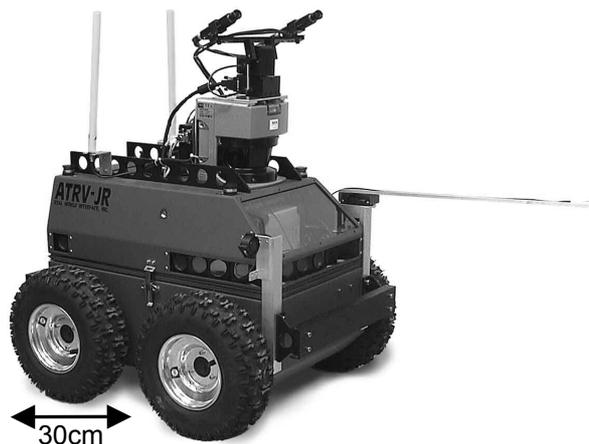


Figure 2: The robot Arthur, a laser range finder mounted on top of the robot, on which a stereoscopic camera system with a pan-tilt unit is installed. The VOCmeter-Vario (see Figure 1) is situated inside the robot, behind the front window. One sensor is mounted on the stiff extension.

### 3.2 Robot

The robot ARTHUR is based on the model ATRV-Jr from RWI which is a four wheeled, skid steered vehicle. The robot is equipped with a Pentium based dual processor system working at a clock rate of 333Mhz, which is integrated into the local network over a wireless LAN connection and operated under Linux. The robot navigation is controlled autonomously, managed by an algorithm that mainly uses the output of the laser range finder (SICK LMS200). The whole unit is mounted on ARTHURS's top (see Figure 2) at a height of about 60cm.

### 3.3 Experimental Setup

The first series of experiments were performed in a 20m long and 3m wide weakly ventilated corridor (one-dimensional environment). The second series was performed in a corridor with similar dimensions but open to one side and in presence of some public traffic.

Three jars filled with acetone or ethanol (with surfaces of 20, 60 and 130cm<sup>2</sup>) were used to simulate a leakage.

The two-dimensional experiments were performed in a seminar room about 12.5m long and 5m wide with a window front at one of the long sides. A larger source with a surface about 320cm<sup>2</sup> was placed in the middle of the room.

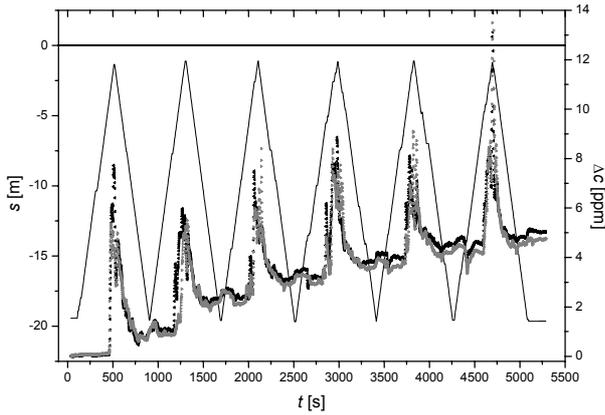


Figure 3: The thin black line indicates the distance between the robot and the jar, the distance of the sensor is about 60cm less, because the sensors are mounted on two stiff extensions on both sides (the left one is shown in Figure 2). The jar was filled at  $t=0s$ . The black and grey dotted lines show the sensor signals of the left and right sensor.

## 4 RESULTS

### 4.1 One-Dimensional Environment

First experiments were performed in the weakly ventilated corridor. The robot drives up and down in the middle of the corridor framing a one-dimensional scenario. A typical measurement is shown in Figure 3; the jar was placed at the end of the corridor ( $s=0$ ), and filled with ethanol at the beginning of the measurement ( $t=0$ ). Two effects can be seen: The constant increase of the base line over time and the well pronounced peak when driving towards the jar. Figure 4 shows the ethanol concentration versus the position of the robot. Starting in a distance about 6m in front of the jar the first significant increase could be seen.

During the second series of experiments, a small, flat jar was used. The robot was able to drive over this jar, therefore it was possible to position the jar in the middle of the floor and get symmetric curves.

The measurement shown in Figure 3 and Figure 4 was performed when the robot was driving around with a speed of 5cm/s, other experiments were made with velocities between 5 and 25cm/s. Driving with 15cm/s results in the maximum peak height, but over the whole speed range no significant differences in signal shapes were observed.

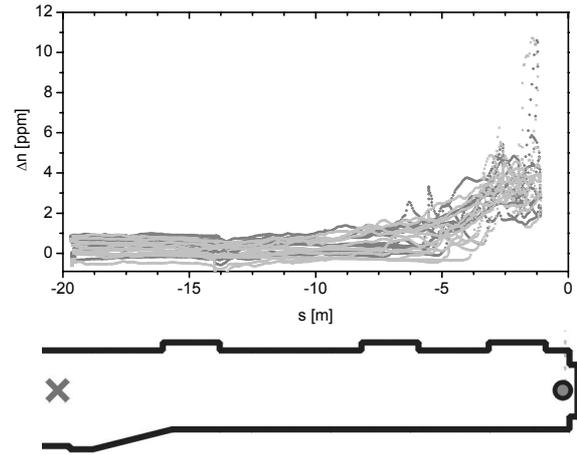


Figure 4: In this figure the same data like in Figure 3 after a linear baseline correction is plotted, the source is located at  $s=0$ .

When stopping, even directly at the source the signal drops down to about 20% of the peak value. This effect may have several reasons, one is the consumption of the metal oxide sensors, another reason might be the absence of whirls, which are generated while driving with the robot.

During this series of experiments the authors varied the mounting of the sensors. The authors were using two 60cm long rods to position two sensors left and right in front of the robot and compare the results of these sensors with those of the sensors mounted on the front edge of the robot, but there is no significant advantage or difference between these positions.

Also the direction of the sensor stick and consequently the sensor was varied with no significant effect on the sensor signal.

### 4.2 Two-Dimensional Environment

After the promising results in the 1D environment, a series of experiments in a 2D environment were performed. The robots path was an angular helix from the outside of the room towards the source in the centre of the room and back.

After turning the robot at the edges of the helix, a short break of 20 seconds was made to allow the sensors (especially those on the rod) to equilibrate again.

A typical result is shown in Figure 5. Although the room was not ventilated, a preferred movement of the gas was identified. The highest concentration of ethanol was found in direction of the rear wall, where the windows are located.

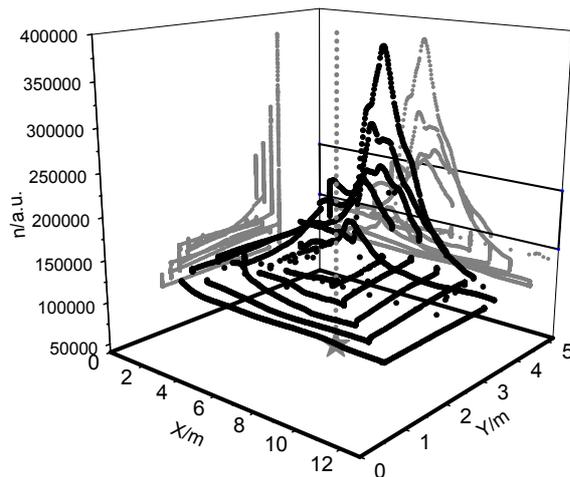


Figure 5: The black dots show the sum of the signals of 4 sensors at the same position (front left edge) but on different heights, the grey dots the projection to the walls. The thick line indicates the shape of the room. The grey star and the dotted line mark the position of the odour source in the centre of the room. The box on the rear wall marks the windows position.

The peaks were higher at the outer part of the room. This situation was almost constant even when repeating the experiment. The reason for this is a circulation. The circulation results of warming the air at the windows caused by sunshine.

## 5 CONCLUSION

The localisation in the one-dimensional environment works perfectly in both cases, the source in the middle of the corridor and the source at the turn point. The maximum peak height matches with the position of the source.

The direct correlation between the peak height and the source position, which was shown in the one-dimensional case, is not recognized in the two-dimensional case. Therefore a well adapted localisation strategy is needed and will be the aim of further activities. Combined with the ability of the robot to navigate autonomously in this environment, an automatic detection and localisation of leakages seems possible for selected cases.

## 6 OUTLOOK

The lowering of the signal when stopping the robot needs further investigation. A small measurement cell with a pumping unit and adjustable flow will be used in future to check this effect. Another advantage of the cell is the direct correlation to the gas mixing station results.

Further experiments will be done, in other environments of the same class. After collecting further data, localisation strategies will be tested and then a feedback to the robot's navigation algorithm will be implemented.

## 7 ACKNOWLEDGEMENT

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