Volatile marks for robotics guidance

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***Abstract*—This paper presents preliminary results of an experimental study about the characteristics of a set of chemical volatiles chosen to mark chemical trails with mobile robots and the influence of the substrate permeability on the ability to detect those chemicals along the time. An algorithm to search and track chemical trails with a mobile robot is proposed. This algorithm was validated by simulations and by tests with a Khepera III mobile robot equipped with a metal oxide-based olfactory system.**

I. INTRODUCTION

Olfaction is frequently used by predators to detect the smell of their preys and follow the corresponding odour plume or odour trail until finding their victims. Another interesting aspect of olfaction is its wide utilization by social animals to help solving complex problems without centralized coordination, namely area search and coverage, and territory marking.

Olfactory based navigation with mobile robots is an area that is gaining an increased interest in the recent years [**?**], particularly the aspects related with tracking odour plumes in the air [**?**], [**?**], [**?**] or water environments [**?**], [**?**]. A relatively less explored aspect is the laying and following of chemical trails with robots. The utilization of volatile chemical marks, that disappear along the time, possess some interesting properties that have been used to simulate search and coverage algorithms [**?**], [**?**], [**?**]. This problem was firstly addressed by Russell [**?**], [**?**] following a camphor trail with a mobile robot equipped quartz crystal microbalance chemical sensors and then by Stella [**?**] using a conductive polymer based gas sensor to follow an adhesive felt ribbon soaked with an odour marker. These preliminary works were not intended to search a trail and were only able to track a given trail at very low speed. Recently, Russell proposed a robotic tongue and tested this device with some biologically inspired searching algorithms to find a chemical mark on the ground [**?**]. Area coverage using chemical marks [**?**], [**?**] is a related research branch that faces some common problems with chemical trail tracking, particularly the problem of sensing chemicals bound to the ground surface. In spite of the works previously described, it is still missing a systematic study of the major aspects related with the utilization of chemical marks for mobile robot navigation. This paper intends to provide some contributions in this way, presenting the results of an ongoing work in this area. When completed, this work will allow implementing mobile robot olfactory behaviours that will be the base for more complex swarming behaviours using environmental chemical marks. Section **??** describes the environmental setup employed during these experiments. Sub-section **??** describes the characteristics of a set of chemical substances with potential to mark chemical trails. Sub-section **??** describes robot olfactory systems that can be used for this purpose, giving special attention to the influence of the sensing nostril in the performance of detection. Section **??** presents an algorithm used to find and follow chemical trails. This algorithm is validated by simulation and by its implementation in a Khepera III mobile robot.

II. EXPERIMENTAL SETUP

A. Chemical markers

A *good* chemical marker to be used by mobile robots needs to be composed by substances easily detected by the robot sensing system, to be volatile enough so it can be detected without physical contact and at the same time it needs to be persistent in order to keep itself time enough on the ground surface. Considering these aspects, the following set of chemical substances was chosen to be used in this work:

TABLE I
CHARACTERISTICS OF THE CHEMICAL MARKERS.

Name	Formula	Molecular mass (g)	Density (g/ml @ $25°C$)	Vapor Pressure ($mmHg$)
α-pinene	$C_{10}H_{16}$	136,23	0,858	—
β-pinene	$C_{10}H_{16}$	136,23	0,866	2 ($20°C$)
α-terpinene	$C_{10}H_{16}$	136,23	0.846	0.8 ($20°C$)
Camphor	$C_{10}H_{16}O$	152,23	0.992	4 ($70°C$)
β-citronellol	$C_{10}H_{20}O$	156,27	0,857	0,02 ($25°C$)
Ethanol	C_2H_6O	46,07	0.789	59.02 ($25°C$)

B. Olfactory System

A mobile robot olfactory system is composed by a set of **gas sensors** usually enclosed inside a gas sampling chamber and by an **olfactory nostril** that is a device responsible for moving the gas of interest in good conditions from a sampling point to the gas sensing chamber.

In this work, a gas sensing system based on commercial metal oxide gas sensors from Figaro Inc. was used to detect the chemical volatiles. Although the ability of the system to discriminate different odours, the experiments were always done with a single target substance, so only the information from a simple gas sensor (TGS2620) was considered.

A good olfactory nostril for the odour trail tracking task should be efficient in the collection process and fast in the odour motion to the measurement chamber. Regarding this device, multiple approaches were tested ranging from direct

Fig. 1. Picture showing a Khepera III robot with a chemical trail detection olfactory system.

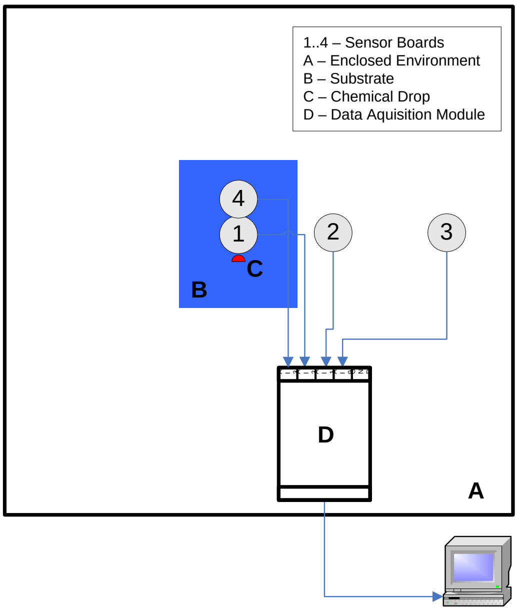

Fig. 2. Representation of the testing environment employed to test the evaporation of different chemicals dropped over different substrates.

exposure of the gas sensor; sniffing with a vacuum pump and finally a setup with the sensing chamber close to the sniffing point. A small fan was placed near the sniffing point in order to stimulate the volatility of the chemicals persistent in the ground surface layer.

C. Robot platform

III. Evaporation tests

The influence of the surface properties on the evaporation rate of the chemical volatiles was tested. Three different substrates with very different permeability were used: polished aluminium plate; premium office paper; and rough cartoon. An almost enclosed volume with a squared area of $1.5 \times 1.5\, m^2$ and 0.5 meters height was prepared (A in Figure **??**). The testing area was isolated with wood walls in order to minimize

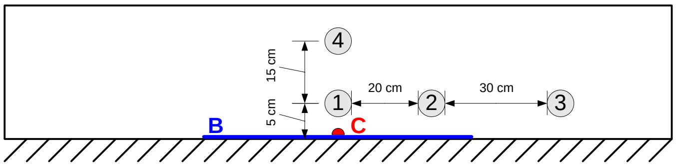

Fig. 3. Side view of the chemical evaporation testing environment.

thermal gradients and consequently avoid noticeable draughts. Four gas sensing boards (1..4) with a metal oxide gas sensor[1] and respective signal conditioning were placed as shown in Figures **??** and **??**. The analog output from those boards was gathered by a National Instruments USB-DAQ6009 data acquisition module with 14 bits resolution (D). For each experiment a chemical drop (C) is released over the substrate under test (B) using a micro-pipette regulated to a volume of 50 μl per drop.

The four sensor boards were placed strategically to collect values at fixed positions representatives of the evaporation process. The sensor 1 was placed just over the drop, at 5 cm height, in order to measure the concentration in the drop proximity. Sensor 4 was also placed over the drop position, but at a higher height of 30 cm from the floor. Sensors 2 and 3 were placed in lateral positions, as can be seen in Figure **??**, so they can measure the spread of the chemical volatile.

A. Surface roughness

Figures **??** to **??** show the output of each gas sensing board during 30 minutes after leaving a drop of alcohol over each of the target surfaces. The following observations can be taken from the response of the four sensors represented in the Figures: It can be clearly seen that roughness surfaces absorb more chemicals, releasing them slowly along the time. This is a useful effect to implement chemical trail following behaviours. Even in this controlled environment, little amounts of turbulence exist what explains the peaks in the output of the gas sensing boards and the relatively small amount of time that takes for the volatiles to reach the peripheral sensors (2 minutes on average until sensor 2 starts detecting the vapours from the drop).

B. Volatile persistence

The persistence of chemical volatiles was analysed in the previous setup, letting evaporate a 50 μl drop of the different chemical over cardboard substrates. Two substances were used in this preliminary study to analyse the effect of volatile persistence on a chemical trail: camphor dissolved with ethanol and pure ethanol. Figures **??** and **??** show the evaporation pattern for ethanol and camphor respectively. It can be clearly seen that the effect of ethanol disappears about 30 minutes after dropping the substance over the surface, but the effect of camphor is still noticeable by some peaks observed in sensor 1 up to one and a half hour after starting the experiment. Another interesting effect of this substance is that it keeps bind to the

[1] Figaro TGS2600

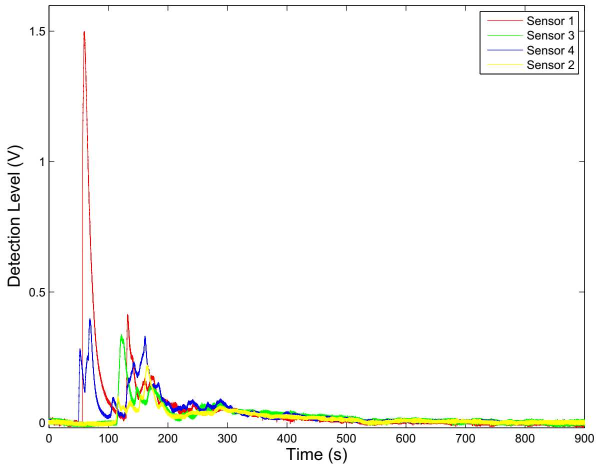

Fig. 4. Alcohol evaporation in a aluminium substrate.

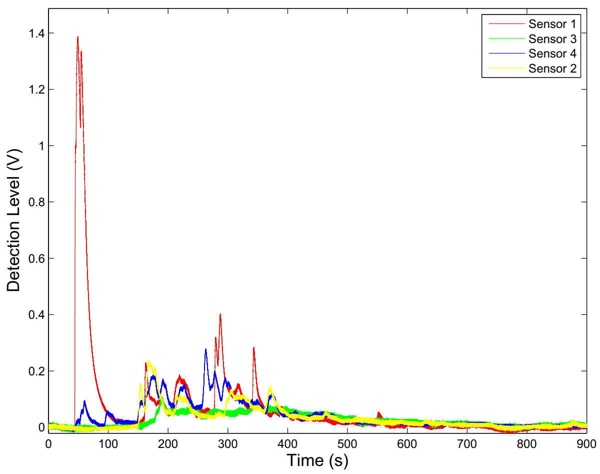

Fig. 5. Alcohol evaporation in an office paper substrate.

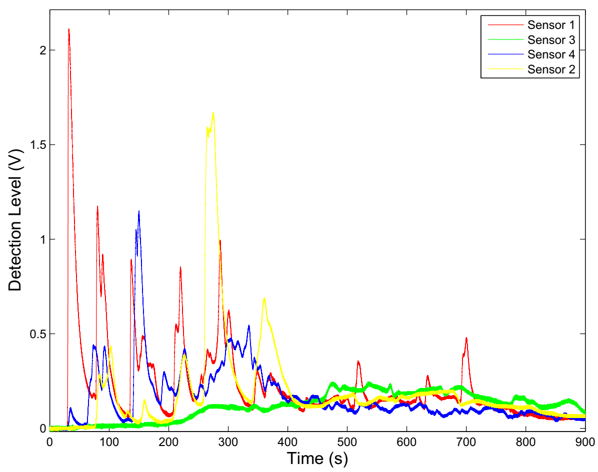

Fig. 6. Alcohol evaporation in a cardboard substrate.

substrate being possible to detect its traces more than 24 hours after releasing the drop over the surface. In this case, to help detecting the traces of the volatile, a small fan oriented to the surface is placed near the inlet port of a sniffing device.

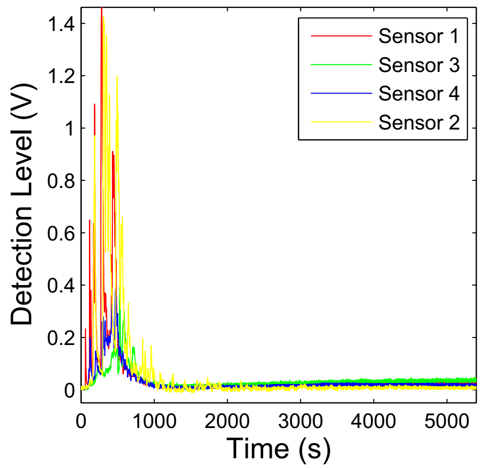

Fig. 7. Alcohol evaporation.

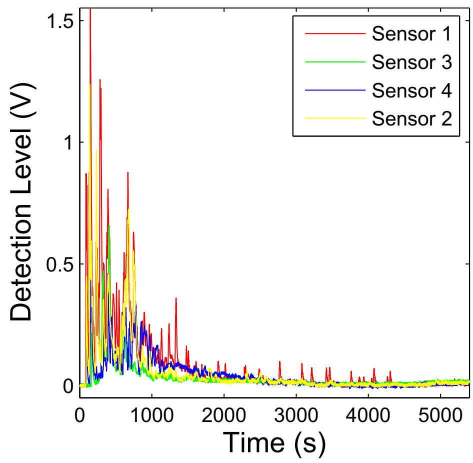

Fig. 8. Camphor evaporation.

C. *Crossing a trail*

Several robot nostrils were tested, but it was concluded by experimentation that the one giving faster and more sensitive results was a nostril with the gas sensors inside a stainless steel gas sampling chamber, placed very close to the ground and sampling the air by means of a miniature vacuum pump. In order to stimulate the releasing of the chemicals bound into the surface, a miniature fan was placed near the nostril inlet dust filter.

A chemical trail was built with 50 μl volume ethanol drops placed every 5 cm along a line. Figure **??** shows the results of crossing that line with a Khepera III mobile robot equipped with the previously described olfactory system. Robot crosses the line and back, stopping for a while between movements. It can be clearly seen that maximum concentration occurs when it cross the center of the trail. Moving away from the center, the concentration becomes smaller.

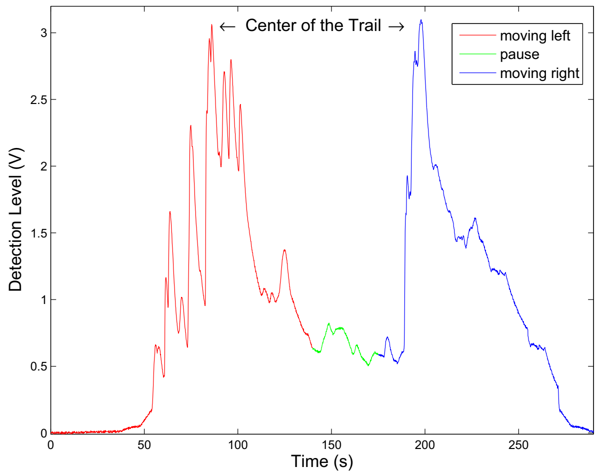

Fig. 9. Gas concentration measured while a Khepera III was crossing a chemical trail made of regular ethanol drops.

IV. TRAIL-FOLLOWING ALGORITHM

The algorithm represented in Figure **??** by a State-Diagram is proposed to find and track odour trails. When a robot has no cue about the possible location for an odour track, it needs to perform a **global search** across the whole search space. After finding an odour cue, the robot tries to **find the odour trail direction** with a series of local movements. If it is not possible to find other odour traces and estimate a trail direction, the robot changes again to the global search state. Otherwise, it **tracks the trail**, while it exists, using zigzag curvilinear movements.

V. CONCLUSIONS

A set of chemical substances was selected and two of those substances, alcohol and camphor, were tested as chemical marks for trail guidance. Although camphor was not the easiest substance to detect with the employed gas sensors, it was the most appropriate substance for the envisaged goal due to its persistence. The properties of the ground used in the experiments and the properties of the olfaction nostril were also studied and its influence in the results were analysed. It was confirmed that surfaces with higher levels of porosity retain the molecules of the chemical volatiles for longer times, and provide a flatter detection characteristic along the time (i.e., the concentration peaks detected are lower, but the concentration level is maintained higher for longer times). Another aspect investigated in this research was the effect of the physical shape of the sensing nostril. It was found that for detecting and tracking an odour trail it is important to use a system that guarantees low latency from the time it takes to sniff the molecules on the ground until those molecules pass through a sensing chamber. Another aspect that was found to be important for an effective detection of

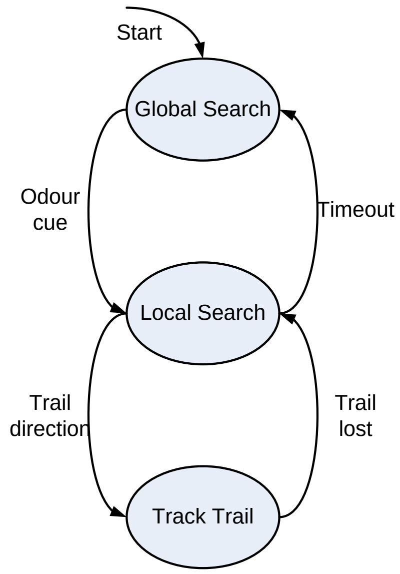

Fig. 10. State diagram for finding and following an odour trail.

Listing 1. Chemical trail finding and tracking algorithm.

```
Init Program
WHILE {not quit}
    Case: Find Trail
        WHILE {trail not detected}
            WalkRandomly()
            AvoidObstacles()
        ENDWHILE
        // something was detected
        State := Search trail
    Case: Search Trail
        IF (try discover trail)
            Spiral Walk()
            IF (detect)
                State := Follow Trail
            ELSEIF (Timeout)
                State := Find Trail
            ENDIF
        ELSE // find orientation
            Search Best Direction()
            Turn to Direction()
            State := Follow Trail
        ENDIF
    Case: Follow Trail
        WHILE {detect trail}
            Follow Trail()
            Zig-zag Walk()
        ENDWHILE
        // not detect
        State := Search Trail
ENDWHILE
End Program
```

a chemical trail, particularly if a large time has passed since the chemical was laid on the ground, was the utilization of some kind of mechanism to stimulate the release of molecules from the surface. In our case a small fan was employed for this effect. Finally, a trail searching and tracking algorithm was implemented in a Khepera III. This work is essentially preliminary. In the future a deeper study of the behaviour of chemical substances to be used as chemical marks will be pursued and a broader range of substances will be included in the study. An optimized sensing nostril will be developed and the chemical trail tracking algorithm will be tested in more complex environments and situations (e.g., to solve a maze).

ACKNOWLEDGMENTS

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