Using Volatile Chemicals to Help Locate Targets in Complex Environments

R. Andrew Russell
Intelligent Robotics Research Centre,
Monash University,
Clayton, VIC 3800,
AUSTRALIA

Lindsay Kleeman
Intelligent Robotics Research Centre,
Monash University,
Clayton, VIC 3800,
AUSTRALIA

Stephen Kennedy
Dept. of Mechanical Engineering,
Monash University,
Clayton, VIC 3800,
AUSTRALIA

Abstract

This paper outlines an on-going project which is investigating the possibility of using chemical signals to locate objects in complex environments. In the current stage of the project the target is to be found in a maze-like structure of interconnecting corridors. This is seen as a step towards the creation of mobile robot systems that can perform such tasks as searching earthquake damaged buildings for survivors or for rescuing broken-down robots which call for assistance by releasing a chemical signal. In this paper the robot design is discussed together with a description of the sensors required for the task. The paper concludes with a description of the search algorithm which is being developed for use by the robot.

1 Introduction

There is increasing interest in using odour detection as a sensory capability for mobile robots [Russell, 1999a]. An obvious application for this would be the use of odour detecting robots as a replacement for sniffer dogs. Amongst other things sniffer dogs are used to detect:

- plant matter, drugs and other materials important to customs officials,
- truffles,
- victims of avalanches and earthquakes,
- escaped prisoners,
- chemical leaks, and
- mines and unexploded bombs.

These animals exhibit functions of chemical sensing, reasoning and mobility, attributes that could be incorporated into robotics systems. Probably because of this kind of potential application the majority of research projects in robotic applications of chemical sensing have addressed the problem of locating the source of a chemical plume [Consi et al., 1995; Ishida et al., 1996; Ishida et al., 1994; Kuwana et al., 1996; Rozas et al., 1991; Russell et al., 1995; Sandini et al., 1993]. In all of these cases except the work reported by Russell, et al. [Russell et al., 1995] and Ishida et al. [Ishida et al., 1999] the chemical plume was established in a region free of obstacles.

In this project we are investigating the possibility of locating an odour source in a relatively complex environment. An odour chemical will be released in an enclosed maze structure and carried to a mobile robot by airflow through the maze. Upon detecting the chemical signal the robot will follow the chemical back through the maze to locate the odour source. This is seen as the first step towards developing a robot which could search through the wreckage of earthquake damaged buildings to locate survivors based on the same odours which guide sniffer dogs. Another potential application would be a rescue robot that could recover disabled robots. For this purpose robots would carry a capsule of chemical to be released as a call for assistance when the robot's batteries failed.

This paper describes the design of the rescue robot and its sensors, and also the odour source and maze structure. The structure of a simple search algorithm is also outlined.

2 The Sensor Suite

In order to navigate through the pathways of the maze the robot has been provided with whisker sensors to detect frontal collisions and a side-looking sonar system for measuring the distance to and relative orientation of the left-hand wall. To ensure that the robot follows the chemical plume up-wind towards its source the robot is also equipped with a chemical sensor and an airflow sensor.

2.1 The Ultrasonic Sensor System

The ultrasonic sensor system consists of a central transmitter that is fed by a 40 kHz square-wave generated by the robot's on-board 68HC11 (see Figures 1 and 4). Twin receivers detect the returned echo which is amplified and rectified to give a logic output when the received pulse exceeds a set threshold. In theory this ultrasonic sensor can be used to determine the range and orientation of the left-hand wall using a single measurement. However, this would require the 68HC11to perform trigonometric calculations. The robot would also need to be reasonably well calibrated in order to make use of the resulting data. Instead the robot uses the following sensing procedure:

Perform a succession of sensing cycles which consist of making an ultrasonic measurement followed by a small turn until the robot is facing parallel to the wall. Range, which is the perpendicular distance to the wall, can then be calculated by the time of flight of the returned pulse:

$$Range = \frac{ct}{2} \qquad (1)$$

where
c = speed of sound in air (approximately 330 m/s)
t = time of flight.

This approximation assumes that the transmitter and receiver are at the same location in space. After this sensing procedure is complete the position and orientation of the wall with respect to the robot is known.

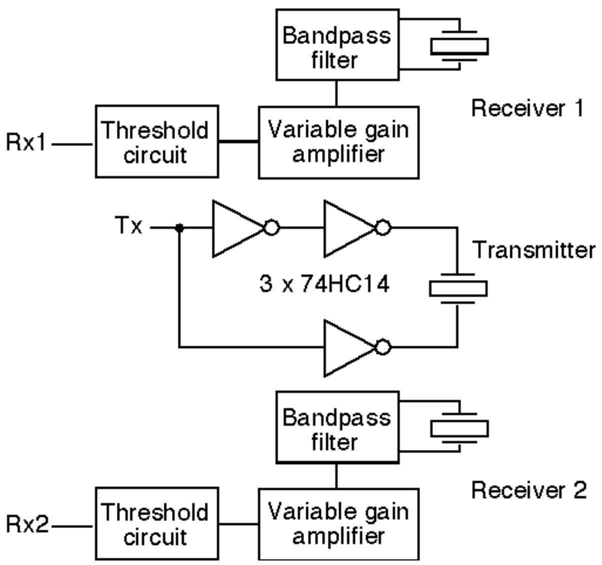

Figure 1 A block diagram of the ultrasonic sensor.

2.2 The Quartz Crystal Microbalance

This sensor uses a quartz crystal as a sensitive balance to weigh odour molecules. A chemical coating on the crystal is chosen to have a specific affinity for the target odorant molecules. When air containing molecules of this odour is drawn over the crystal some of the molecules become temporarily attached to the coating. This increases the mass of the crystal and lowers its resonant frequency. . A simple model proposed by Sauerbrey predicts the effect of small amounts of added mass:

$$\Delta f = -\frac{2f^2\Delta m}{rv} \qquad (2)$$

where:
f = change in crystal resonant frequency
f = crystal resonant frequency
m = increase in mass of the crystal per unit area,
r = density of crystal material
v = velocity of sound in the crystal material

Thus, for a 10Mhz crystal with a surface area of about $4.4x10^{-5}$ m^2 a mass loading of 2 nano-grams will give a frequency shift of more than 1 Hertz. In this experiment a crystal coated with silicone OV-17 was used to detect the target odorant camphor. In order to use the coated crystal in a sensor it must be incorporated into an oscillator circuit. A block diagram of the sensor circuit is shown in Figure 2. It incorporates a fixed 10 Mhz oscillator as well as the sensor oscillator and a D-type flip-flop to derive the difference frequency. This circuit consumes 55 mW and the complete sensor has a response time of the order of seconds.

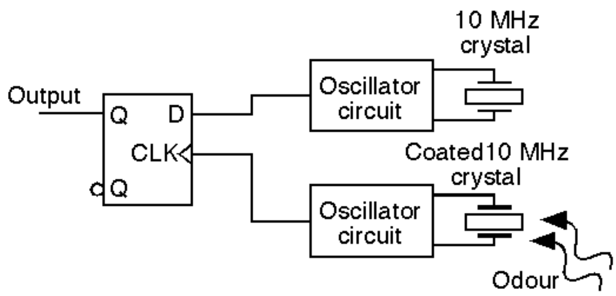

Figure 2 Quartz crystal microbalance sensor circuit.

2.3 Airflow Sensor

Measuring wind velocity and direction is difficult at low velocities. We have developed a novel active airflow velocity and direction sensor specifically for use with miniature mobile robots [Russell, 1999b]. This device works at low wind velocities and its simplicity, potential for miniaturisation and low power consumption make it suitable for mounting on small robots such as the RAT robot used in this project. The key feature of the sensor is a flat plate or paddle rotated by a precision dc motor (see Figure 3). In still air the rotational speed of the paddle is constant. However, when situated in an airflow the paddle slows down when moving upwind and speeds up when moving downwind. This variation in paddle rotational speed is measured by an optical encoder and used to infer both wind direction and velocity. The difference between maximum and minimum paddle velocity is related to wind strength. Maximum paddle velocity will occur when the paddle is travelling in the same direction as the wind. This can be used to determine wind direction.

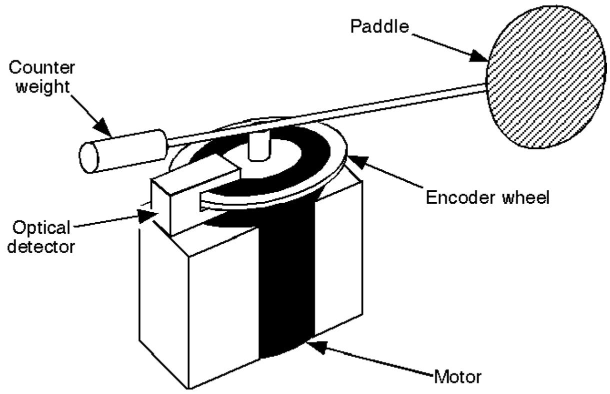

Figure 3 The main components of the airflow sensor.

3 The Robot

The mobile platform used in this experiment is based on the Reactive Autonomous Testbed (RAT) robot which was designed in the Intelligent Robotics Research Centre at Monash University as a simple and inexpensive robot that could be built in large numbers. The basic RAT robot is driven by two side-by-side wheel units with a free-running ball as a third point of contact to provide balance. Optical encoders are attached to the wheel drive motors to measure wheel movement. This robot is equipped with front whiskers to act as close proximity sensors. Onboard intelligence is provided by a Motorola 68HC11 microcontroller. As well as controlling the movements of the robot and providing diagnostic tones the 68HC11 runs the whisker, ultrasonic, odour and airflow sensors and coordinates the overall search strategy. A photograph of the RAT robot including all of the sensors used in this project is shown in Figure 4.

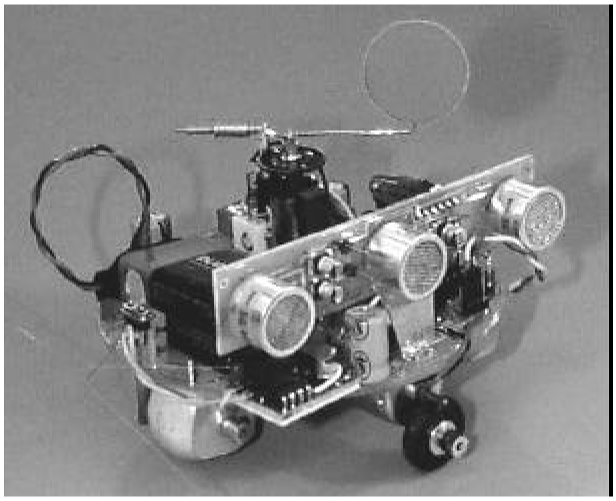

Figure 4 The rescue robot: a RAT robot equipped with ultrasonic wall-following sensors, an airflow sensor, whisker bump sensors, and a chemical sensor.

4 The Experimental Environment

To allow us to study the intended applications the robot is required to navigate in an environment constrained by obstacles. At the same time it must be able to detect odour concentration and airflow so that this information can be used to move towards the odour source. With these considerations in mind we built the enclosed maze structure shown in Figure 5. This maze is constructed from 470 mm by 270 mm by 270 mm cardboard boxes and can be quickly rebuilt in other configurations. A cooling fan powered via a variable transformer provides an adjustable airflow through the maze. In order to keep the airflow within the maze clear plastic sheeting covers the pathways in the maze.

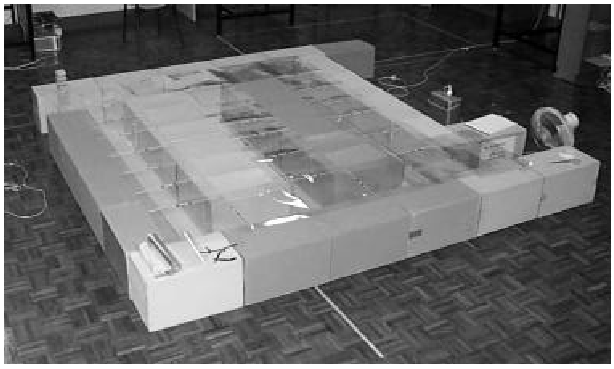

Figure 5 The experimental environment - a simple maze with induced airflow.

The odour source consists of six short lengths of cardboard tube glued together and mounted on a block of wood. This provides a large surface area of semi-absorbent material which is sprayed with a solution of camphor dissolved in alcohol.

5 The Search Algorithm

In the rescue scenario that is the basis for this project our robot will wait at the exit of the maze until it detects the chemical signal. It will then move into the maze using the ultrasonic sensor to maintain a constant separation from the left-hand wall. The robot will move straight ahead or turn left if there is a left-hand branch in the corridor. Right-hand branches will not be detected by the ultrasonic sensor and therefore will be ignored so far as wall following is concerned. However, right-hand branches will be detected if they affect the airflow direction or chemical concentration. In most cases wall-following behaviour alone will not lead to the chemical source.

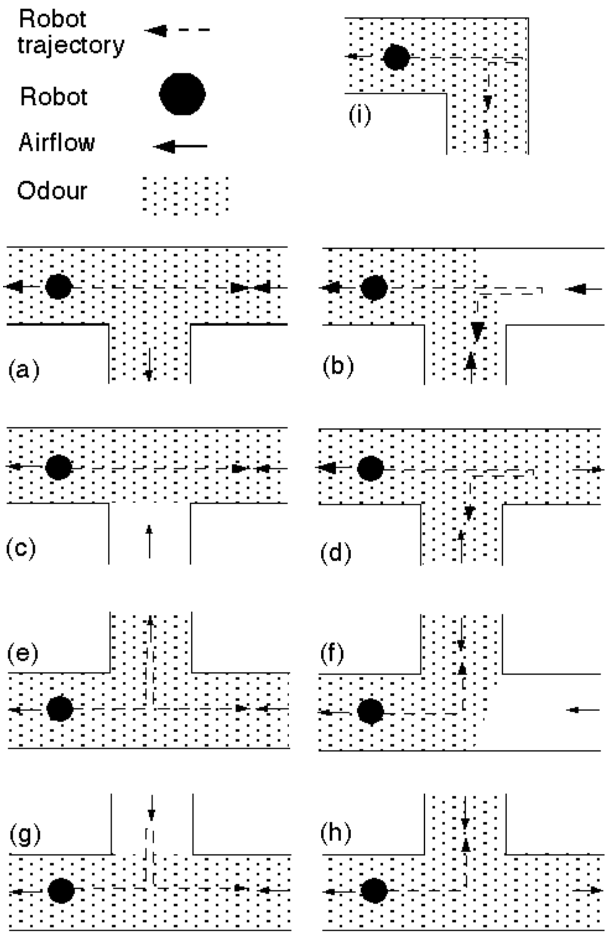

Figure 6 The different situations encountered by the rescue robot.

Figures 6a to 6h show a number of situations that the robot could meet at a junction in the corridor. In each of the cases where the robot needs to back-track to follow the correct path (Figures 6b, 6d, 6e and 6g) it will encounter a situation where it loses the odour signal (Figures 6b and 6g) or where it finds itself travelling down-wind (Figures 6d and 6e). Therefore the airflow and odour sensors can be used to trigger a back-tracking behaviour. If the robot enters a blind leg of the maze then the reduced airflow can also be used to trigger back-tracking. This is not essential for successful odour source location because the left-hand wall following behaviour will eventually lead the robot out of the blind leg. The front whisker sensors will be activated at a left-hand turn in the maze or at the end of a blind leg. Backing away from the wall and turning 90 to the right will deal with these two situations.

The proposed control scheme is largely reactive involving the robot immediately responding to its sensor readings or responding after a fixed delay. This delay is to avoid unnecessary direction changes as a result of erroneous sensor readings that will occur due to fluctuations in the airflow, etc. Figure 7 shows the control scheme presented in the form of Brooks' subsumption architecture [Brooks, 1989]. Currently the software for controlling the wheel movements of the robot and the sensing functions of the sensors has been successfully completed. We are currently engaged in implementing and testing the full control scheme.

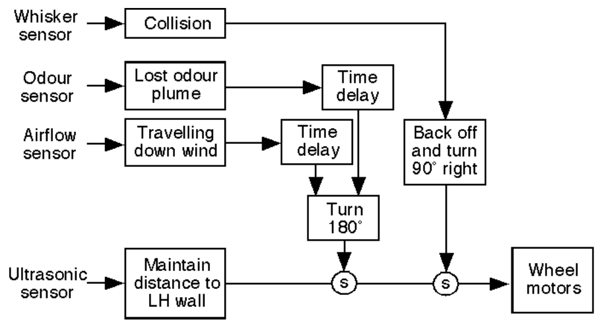

Figure 7 Proposed control scheme for the rescue robot.

6 Conclusions

Robots could provide the mobility and sensing attributes of sniffer dogs. Animals require extensive training, they must be cared for by an expert handler, their attention span is short and they suffer from fatigue. Robotic systems could offer improvements in all of these areas. There are also environments where it would be physically impossible for animals and their handlers to operate. These include high concentrations of poison gas and nuclear radiation. Robots could be hardened to withstand these conditions and could even be considered to be disposable if they became too contaminated.

This paper reports on a project which aims to develop robotic systems which can perform some of the tasks currently undertaken by sniffer dogs. It is also envisaged that this technology could be used to locate disabled robots if a chemical marker is released when the robot's batteries fail. The released chemical would follow a path that indicates a route between the rescuing robot and the disabled robot (though the path may become too constricted to allow the rescue robot to pass).

A robot system has been constructed for investigating the sensing and control requirements for locating an odour source in a maze of narrow corridors. Future work will be directed towards locating more sensitive and selective chemical sensors, providing the robot with more sensors to monitor its environment and improving the rough-terrain capability of the robot vehicle.

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