Odor Source Localization with Mobile Robots

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Because of their excellent olfactory sense, dogs are often used to find bombs, mines, drugs, or people buried by avalanches. For such applications, autonomous mobile robots could be used in the future. Electronic sensors already exist for a wide variety of substances, and are still being actively researched. Mobile robots are an important area of research, too. But beyond a good sensor and a suitable robotic platform, a third component is required: odor source localization algorithms – and due to the complex propagation of odor molecules in the air, tracking down odor sources is still a big challenge.

The sense of smell is very important for many animals. Olfaction is used for scavenging and inspection, mating, recognition, hunting, and avoiding predators. Humans also use smells in their daily lives, though their senses are much less acute than those of dogs or rats [1]. Largely due to this special ability, these animals are often used in search and rescue operations, at airports or border controls to search for drugs or explosives, and for humanitarian de-mining.

In mobile robotics, olfaction has not yet been widely used. Recently, however, many electrochemical sensors are being researched and developed which may allow this to change. In addition to general-purpose sensors for the detection of alcohol, harmful gases, and air contaminants, there are also sensors for the detection of explosives. The highest quality current sensors can even rival the sensitivity of a dog's nose.

Such sensors, if deployed on a suitable platform, could replace the dog in many applications. In future search and rescue operations, for example, small robots could be used to find human bodies or hazardous substances. Other potential applications include humanitarian de-mining, bomb detection after threats or alerts, or even simply locating leakages in industrial plants.

These applications all have a common structure: one or several sources are constantly releasing molecules, which are then dispersed in the air by mainly advective flows (wind). The goal is to find the source by sniffing air at various places, and perhaps measuring the wind. While this may sound like a relatively easy task, odor source localization is actually quite challenging.

The complex structure of plumes in the air

Air movements exist at all scales. Large and strong eddies (air currents) are perceived as wind and tend to transport air in one principal direction. The smaller, sometimes barely perceptible, eddies, however, additionally stir the air in an unpredictable way. Odor molecules follow this airflow and are thus spread in an irregular, packet-like fashion. This can be observed over a smoking chimney, for example. When traversing such a field, high concentrations (odor packets) may be measured right next to very low concentrations. These patterns are also highly unstable and change rapidly.

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In addition, changing wind conditions can transport the chemicals in different directions. This is called meandering, and is a unique feature of odor plumes; such effects don't exist in sound or light waves. Furthermore, intermittent sources may yield an even more complicated distribution.

Inspiration from biology

A robot tracing such a plume measures a highly irregular signal, as described. Sporadic peaks appear when its sensor encounters an odor packet, rendering gradient-based search techniques essentially useless.

All is not lost, though, as we can see several examples in biology of natural systems that have developed methods for approaching this problem. Insects such as moths, for example, fly in a zigzag pattern towards their mating partners. What they are doing is a repeated lateral traversal of the odor plume coming from their potential partner, advancing a little bit upwind with each crossing. Ants use the same strategy when they follow pheromone trails. Using an algorithm such as this, a robot is also able to locate an odor source [2]. The time required to localize the source is mainly dependent on the upwind angle—choosing a steep upwind angle yields a higher upwind speed (and therefore a higher speed towards the source), but lowers robustness to plume meandering. However, this trade-off can be optimized with adaptive strategies. To account for the irregularity of the signal, a robot considers itself to have left the plume only after not encountering any packets for a given time; thereby, ignoring transient decreases in measured concentration.

Another algorithm, also inspired by animal behavior, is called the spiral surge algorithm [3]. Here, the robot moves along a outward spiral path until it perceives a certain concentration and then moves straight upwind. As soon as it looses the scent, it starts spiraling again. The size of the spiral can be decreased when moving closer to the source. Even though distance to

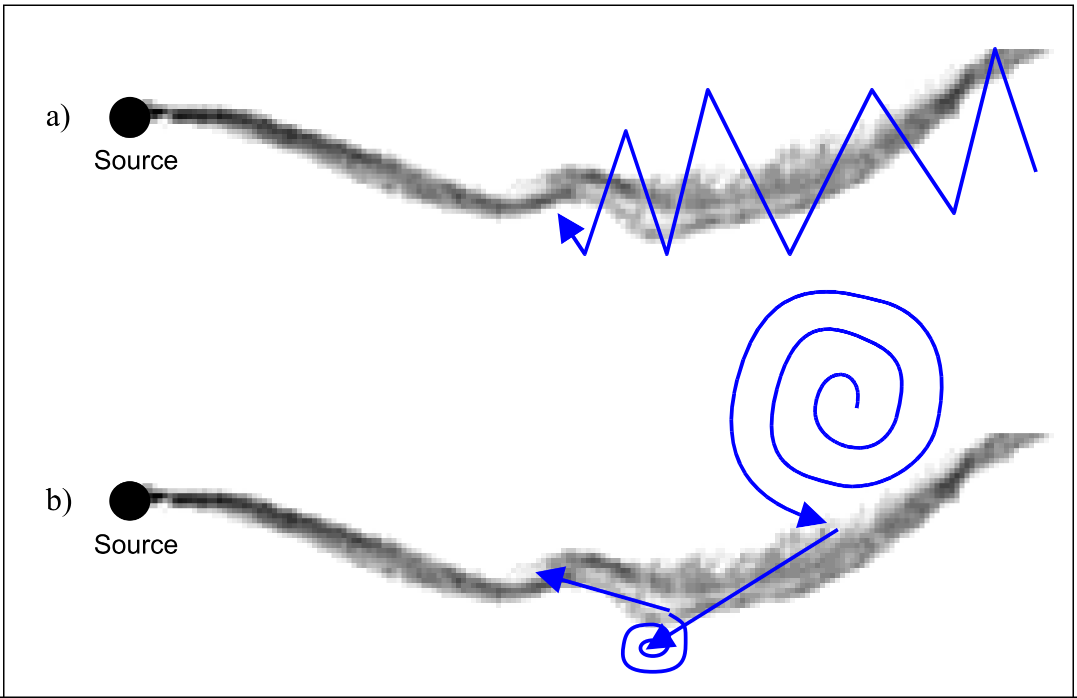

Figure 1: Zigzagging (a) and spiral surge (b) are two bio-inspired odor source localization algorithms for single-robot systems.

the source is usually not known, it can sometimes be estimated with the amplitude of the concentration peaks and the spatiotemporal intervals between them.

Both the spiral surge and the zigzag algorithm work reasonably well in environments with sufficient wind flow. In calm environments, however, these algorithms in their original version are noticeably less effective. Beyond modified versions of the spiral surge algorithm, approaches using plume mapping have been studied. The robot first systematically traverses the environment to measure concentration at various points. The sources can then be localized on the resulting concentration map. If time allows, the robot may traverse the environment several times so that the concentrations can be averaged and the map quality consequently enhanced.

Another, rather indirect, approach consists of avoiding the odor instead of following it [4]. Observing the robot trajectory can then highlight potential source locations to investigate.

Odor source localization with a swarm of robots

A critical characteristic of odor source localization algorithms is energy consumption, which is largely determined by the time it takes to find the source and the distance traveled. Time can also be a constraint in itself in many applications, especially those in the field of security.

To speed up the search, multi-robot systems have been proposed [3]. By deploying several robots, the time required to find the first odor packet (first hit) can often be significantly reduced, and if the robots communicate with each other and collaborate, the time to track the plume to its source can be decreased as well. Furthermore, multi-robot systems provide a greater robustness against hardware failures.

Multi-robot systems for odor source localization have not been well studied so far, but are now the topic of a research project funded by the Swiss National Center of Competence in Research on Mobile Information & Communications Systems (NCCR-MICS) and carried out by the Swarm-Intelligent Group (SWIS) at EPFL. To test multi-robot algorithms, the researchers are using Khepera III robots (K-Team SA, Yverdon) that have been equipped with an odor sensor (MicroChemical Systems SA, Corcelles), a smoke sensor, and a wind sensor. Air is ‘sniffed’ with a miniature pump and delivered to the odor or the smoke sensor, which closely resembles the respiration systems of humans or animals. These robots, despite being

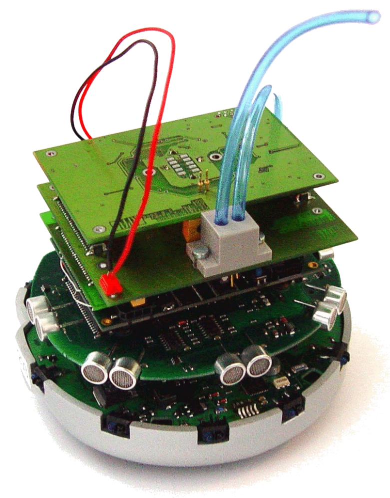

Figure 2: A Khepera III robot with the odor and wind sensor modules (prototype).

just 12 cm in diameter, are running an embedded distribution of Linux and can communicate through an ad hoc WLAN 802.11b network. The odors used for experimentation are alcohol vapors, smoke, and water vapor.

In the near future, experiments will be carried out in a wind tunnel at EPFL. Since the conditions in the wind tunnel can be closely controlled, experiments can be repeated with various algorithms and parameters. This allows comparison of different algorithms under the same setup and the same conditions. For these experiments, ten such robots will be used, so as to study the impact of collaborative approaches on system performance. The algorithms themselves, though, are scalable, and could one day be just as easily deployed in a swarm consisting of hundreds or thousands of robots, depending on the number of sources, the area to search and the desired localization speed.

Applications and outlook

The field of potential applications for odor source localization algorithms is vast. In principle, robots could one day perform all the same search tasks that are currently carried out with dogs or other trained animals. However, locomotion over complex terrain is still largely an open challenge in the current state of mobile robotics; significant additional developments will be necessary before disaster area applications become feasible. Applications in simpler environments (e.g. buildings), though, could soon be possible.

References

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