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Synthesis of odor tracking algorithms with genetic programming

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A B S T R A C T

At the moment, smell sensors for odor source localization in mobile robotics represent a topic of interest for researchers around the world. In particular, we introduce in this paper the idea of developing biologically inspired sniffing robots in combination with bioinspired techniques such as evolutionary computing. The aim is to approach the problem of creating an artificial nose that can be incorporated into a real working system, while considering the environmental model and odor behavior, the perception system, and algorithm for tracking the odor plume. Current algorithms try to emulate animal behavior in an attempt to replicate their capability to follow odors. Nevertheless, odor perception systems are still in their infancy and far from their biological counterpart. This paper presents a proposal in which a real-working artificial nose is tested as a perception system within a mobile robot. Genetic programming is used as the learning technique platform to develop odor source localization algorithms. Experiments in simulation and with an actual working robot are presented and the results compared with two algorithms. The quality of results demonstrates that genetic programming is able to recreate chemotaxis behavior by considering mathematical models for odor propagation and perception system.

1. Introduction

Around the world, different environmental conditions and sometimes negligence produce hazard zones that endanger population. Such disaster areas affected by hurricanes, earthquakes, fires and nuclear catastrophes need to be restored as soon as possible without risking more lives. Rescue teams work intensively to diminish the effects, but occasionally they cannot reach the complete area due to toxic environments, the potential presence of explosive materials, collapses, or a simple circumstance like inadequate space. Rescue robots have received considerable attention in recent years, thus providing solutions for those scenarios where human rescue teams are unable to work. Today, a major trend in robotics research is to incorporate different sensor capabilities inspired from solutions of the natural world. The idea is that as soon as robots are able to see, hear and touch, technology will be able to emulate the human capabilities for searching, mapping, exploration and localization of different targets, such as lost or injured people, safe trajectories, gas leaks, explosives, to mention but a few. Nevertheless, these capabilities may not be robust enough for real disaster scenarios due, for example, to poor visibility generated by the presence of obstacles that increase the difficulty of reaching specific target zones. A promising research area that could tackle such limits is based on the inclusion of olfaction capabilities inspired by solutions found in the animal kingdom. Animals use the sense of smell for diverse tasks like inspection, recognition, mating and hunting, despite not always being its principal perception mechanism. For example, dogs are trained to accomplish search and rescue operations within disaster areas, airports and borders. In this way, they use primarily the sense of smell to localize drugs, explosives, chemicals, hazardous substances and even persons [1]. Moreover, perception of the environment composition (odor molecules and concentrations) through olfaction might develop into a set of strategies that could be implemented within a sniffing robot so that it could find the direction of odor trails and follow them until it reaches a saturated zone [2] to finally locate and detect toxic gas leaks, the origin of a fire, and so on.

Nevertheless, an optimal perception system like those encountered in simple organisms is not currently available since artificial sensors differ significantly from their biological counterparts. Moreover, the algorithms based on natural processes attempt to emulate the behavior of some animals, such as casting, and sweeping spiral [3] without reaching the same level of performance; i.e., the odor source is not located with high accuracy or it requires a lot of time to be reached. In our work, we believe that the difference between both systems may be due to the fact that the natural smell sense, unlike an artificial perception system, is evolved over many years until it acquires a way of locating the

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odor. Thus, the idea of synthesizing artificial odor tracking strategies will be developed through artificial evolution; in particular, the application of genetic programming in combination with our artificial nose. Next, we review the main works devoted to odor source localization.

1.1. Related work

In the literature, there are many algorithms that aim to increase the efficiency of odor source localization from the viewpoint of sensor usefulness. The techniques are generally classified through the following functions: *chemotaxis*, *anemotaxis* and *fluxotaxis*, depending on the environment and capabilities of odor sensors. This research centers on the development of an artificial nose and in particular this paper deals with the development of chemotaxis algorithms. Traditionally, the chemical gradient derived from certain chemicals in the environment is the basis for orientation and movement of an agent – mobile robot – and it forms the base of chemotaxis algorithms. In general, the approach mimics the perception of odor using single or multiple sensors placed at different positions while calculating gradient responses over time [2]. The onboard or remote computer is responsible for analyzing the signals and their variations with respect to time and space. The first robot charged with odor source localization was presented by Rozas et al. in 1991 [4]. The design consists of following odor gradients by taking two or more measurements by one sensor from different positions at different times. In this algorithm, the robot had to measure odor concentration at four different positions. Additionally, if the new measurement was smaller than the previous one, the robot returns to the last position. Through this routine, a robot takes a lot of time to get closer to the source. Later, in the mid 1990s the first sensor design used to obtain a measurement from two positions at the same time was presented by Ishida et al. [5,6]. This odor compass requires rotating the probe 360°, a process that took 20 s to obtain a direction and about one minute to recover from its initial state. Results showed that the system points to the trail direction but not always to the source position. Afterwards, a new stereo architecture implemented on a Koala mobile robot used measurements at different times and positions to obtain a gradient [7]. Nevertheless, the robot needed to be very close to the source for detection. Then, a mechanical implementation was presented [8] in which motor speed on each tire was proportional to their averaged concentration issued from an array of sensors. Hence, the robot was forced to turn when it reached some virtual walls, thus staying near to the odor source. Again, the robot needed to pass close to the source to detect the odor. Recently, work was presented using an unmanned aerial vehicle and a pseudo-gradient algorithm [9]. The Airrobot AR100-B micro-drone was used with an autonomous routine based on wind information and chemical gradient, sensed around the environment. Due to turbulence generated by its propellers, the drone should stay in the same place for a long time between measurements.

The principal drawback of previous algorithms were related to the sensors processing time since it took a lot of time to be ready for a second measurement (more than one minute). Some strategies even required more time since they need to cover the whole area several times (more than 20 min). Also, the odor source was not always reached due to multiple local maxima placed near the odor source. This happens because vapors are volatile and tend to homogenize the whole area, but in the case of constant gas leaks, maximum concentration is always at the exit of odor source. Sometimes the difference between both nostrils is provided by an airflow that helps us to circulate the odor around the system, creating a trail at the robot's rear part, and, as a consequence, sensors are constantly saturated by the same odor. Moreover, some systems, besides using chemotaxis, also collect wind information (anemotaxis), which is the most popular technique for outdoor environments. Thus, while considering that perception of wind speed is imperceptible for humans and common anemometers beyond 0.1 m/s [10], and that anemotaxis techniques are not appropriate for indoor environments that have small air currents. In this work, we provide evidence that considering only the chemical gradient is enough to reach an odor source indoors. With this as a foundation, all techniques could be improved based on chemical gradient, wind speed, mass flux, alone or in combination. This includes the use of robot teams or swarms where each one of them can have different behaviors or cooperate to reach bigger zones that will decrease the tracking time.

Robots could be designed to learn to use their odor sensors while considering the limitations at the moment of perceiving the environment. Comparatively, some research about perception systems that learn to discriminate odors was presented in 1999 [11]. In this case, an artificial neural network simulates the olfactory sensory neurons; thus, enabling discrimination of organic vapors. A similar approach in 2001 imitates the olfactory bulb including rank-order filtering over artificial neural networks [12]. Later, in 2004 the mathematical model for all biological olfactive layers using artificial neural networks was achieved [13]. On the other hand, Continuous Time Recurrent Neural Networks (CTRNNs) presented on 2013 [14], evolved odor source localization with a simulated robot equipped with a single chemical sensor and wind direction sensor. Schaffernicht and coworkers in 2014 [15] modeled and mapped the distribution of gas events, as well as detection and non-detection of a target gas using Bayesian Spatial Event Distribution. Recent work by Zhang and colleagues discusses localizing several odor sources [16], implementing a method based on niching Particle Swarm Optimization (PSO).

Moreover, to accomplish odor source localization, it is fundamental to consider the characteristics of the sensor with respect to desaturation time, concentration difference between sources, and reaction time. In our work, these features and their mathematical models are the basis of a learning perception system, which is used to derive a new technique that offers better results. The goal of this research is to obtain an algorithm that validates the use of chemical sensors to track and locate odor sources, especially when other sensors are limited or unavailable. Thus, the method relies on the perception of chemical odors while avoiding other sensors such as anemometers, cameras, sonars, and so on. In particular, the aim is to design algorithms, based only on olfaction (chemotaxis), that are able to follow straighter paths, thus reaching the source faster in comparison with current techniques. The algorithm for indoors obtained by genetic programming considers the mathematical models for odor propagation, and the perception system implemented into an unmanned ground vehicle (UGV) that looks for an optimal way of achieving the task in environments with imperceptible air currents for humans, while considering the limitations and advantages of the implementation.

Our paper is organized as follows: the problem statement is presented in Section 1.2 followed by a summary of our contributions in Section 1.3. In Section 2 the perception systems for chemical gradient are detailed. In particular, we describe the odor propagation model in 2.1, the chemotaxis technique in Section 2.2, and the artificial nose in Section 2.3. Section 3 details the chemotaxis algorithms. In Section 4 the description of our proposed methodology is comprehensively addressed. The simulation framework in Section 4.1, and the genetic programming method in Section 4.2. Then, in Section 5 the experimental setup and results are discussed. Finally, Section 6 provides the conclusions together with possible future work.