A Robot Odor Source Localization Strategy Based on Bionic Behavior

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A Robot Odor Source Localization Strategy Based on Bionic Behavior

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Abstract. In this paper, a robot bionic odor source localization algorithm based on kinesis response and tropotaxis behavior of flatworm is proposed, the algorithm does not need to detect wind direction information and odor absolute concentration information. Experiments show that the proposed algorithm is not affected by both wind direction and wind speed, only by judging the rate of change of odor concentration, which improves the searching efficiency, has good stability and environmental adaptability. it is a reliable initiative olfactory strategy with simple, search speed, high efficiency advantages.
Key Words. flatworm, bio-tropotaxis, Mobile Robot, Indoor environment, odor navigation

1. Introduction

In recent years, the use of mobile robots and gas sensors to achieve the odor source localization has become a research focus. Have olfactory function of the robot can engage in odor-related areas of work. Including the detection of land mines, search for explosives, search and rescue victims, poisonous gas detection, fire alarm, detection of various types of hazardous chemical storage containers or pipeline leakage and repair, can also carry out prospecting. In fact, The most critical problem of the robot's olfactory task is to search, locate and identify the odor source.

The robot can find the odor source by tracing the plume, the so-called plume refers to the feather-like trajectory of smell molecules released by the scent source in air [1]. Hayes [2] decomposed the problem into three sub-tasks, that plume found, plume cross, odor source confirmed. As early as 1991, Rozas [3] used the developed artificial nose to conduct research in this area, installing the artificial nose on a mobile robot to find the source of the odor by tracking the concentration of the gas in the test environment. Similarly, it is to install a pair of gas sensors on the mobile robot to compare the output of the two sensors so that the robot moves in the direction of high concentration. Li suxia proposes the algorithm of odor source detection by using the camera small hole imaging model and the component equation model of odor active olfaction [4]. Chen Yicun (et al) get good result in source localization and active olfaction [5-9]. but due to the influence of turbulence, the concentration distribution in the gas diffusion process is not regular and smooth, so robots use only the gas concentration gradient to search for odor sources less efficiently. To address this issue, Ishida [10] and his colleagues are inspired by the moth's upwind tracking of pheromones. Using four gas sensors and four wind speed sensor made the odor direction detection device, which made full use of the odor information and the wind direction information to complete the taste source search. Based on this, they also studied some new algorithms. By searching the smoke plume along the concentration gradient and tracking the smoke plumes along the wind direction. Pyk [11] developed a mobile person equipped with six arrays of metal oxide gas sensors and wind vane wind direction sensors moth and used it to simulate the moth's tracing movement of pheromone traversing the wind direction and the upwind direction in the wind tunnel. It find the source of taste at a distance of 4 m. In recent years, Marques [12] and Loutfi [13] also made great achievements in using mobile robots to study the taste source localization.

In this paper, we propose odor source localization strategy for robots that is based on the kinesis response and bio-tropotaxis behavior of flatworm [14] and have validated the effectiveness, speediness and independence of the wind direction and the odor of the search strategy in simulation experiments concentration characteristics, this paper validates and analyzes its performance through experiments.

2. Robot Odor Source Localization Strategy Based in Flatworm and Bio-tropotaxis Behavior

2.1 Bionic principle

Many animals look for odor source(food or heterology) by tracking plume, but do not measure the average concentration. For example, the moth can detect the surrounding gas with the antenna while exercising, and there is not enough time to obtain the mean value of a certain point. There are some ways to find the odor source by obtaining the instantaneous change in the concentration of smoke in the plume.

Kinesis response [15]: This is a phototactic reaction mechanism of flatworm, which prefers darker areas to light intensity. Increasing its turning rate as light intensity increases and does not directly depend on current the absolute intensity of light, but the rate of change of light intensity, the faster the light intensity changes, the greater the steering rate, the faster the trend toward darker areas.

Tropotaxis [16]: An tropotaxis mechanism is that an animal uses two or more sensors at the same time to produce an instantaneous estimate of the same or opposite direction of the concentration gradient. It use two or more sensors that distribution in space to detect the odor.It is decapoda crustaceans, flying Insects, reptiles, insects commonly used to track odors stimulate the tropotaxis mechanism. This is useful when tracking turbulent flow plumes.

2.2 Odor source localization algorithm

The flatworm's kinesis response is typical of bio-tropotaxis behavior independent of absolute intensity. When the light intensity increases, it will increase its own turn rate, and does not directly depend on the absolute intensity of the current light, but the rate of change of light intensity, the light intensity changes faster, the turn rate is larger, faster to darker area. A tropotaxis mechanism is that the animal produces an instantaneous estimate of the same or opposite direction of the concentration gradient by comparing two or more sensors at the same time. Based on this bionic principle, the difference in concentration between the two positions is detected to make direction estimation. According to the Kinesis response, bionic odor source localization strategy based on the tropotaxis behavior is proposed, which does not rely on the absolute sensor concentration and improves the searching efficiency of the robot, and can be independent of the wind direction.

Definition C is the current concentration, Cmax is the maximum concentration from the initial to the nth position, V is the concentration change rate, Vmin is the set minimum change rate, and Vn is the concentration change rate at the nth step. Vn = (Cn-Cn -1) / Cn-1, where n is the nth sample to start the search. a is the angle with the current direction of the robot, dmin is the minimum step size, d is the current step, ka, kd is the change factor related to V, which determines the change of a and d. According to the dynamic stimulus response, an = kaan-1, dn = kd * dn-1. When the repetition conditions are not satisfied, and Cn changes slightly with respect to Cmax, it is the source of taste, and ε is the absolute value of the difference between the two. Search strategy as shown in Figure: First, the robot random search to a given step, any angle forward, did not detect the gas, the same step size, random left or right turn an angle a until detected gas, then according to the rate of change of the gas concentration in the last two steps of the robot determines whether the robot turns left or right and changes its step. When the sensor acquisition data to meet the robot stop conditions, that place of taste, as shown in Figure 1.

Sampling, α as the angle between robot and the current direction of advance, d min is the minimum step size, d is the current step size, k is the change factor related to V, which determines the change of α and d. According to dynamic bionic response principle, $\alpha_n = k_\alpha * \alpha_{n-1}$, $d_n = k_d * d_{n-1}$,the initial value is set according to the visual situation, the coefficient value rules such as formula (1), (2). Decided to turn anticlockwise a or clockwise turn a According to the trend of the mechanism to determine that the strategy to determine the steering part of the schematic diagram shown in Figure 2.

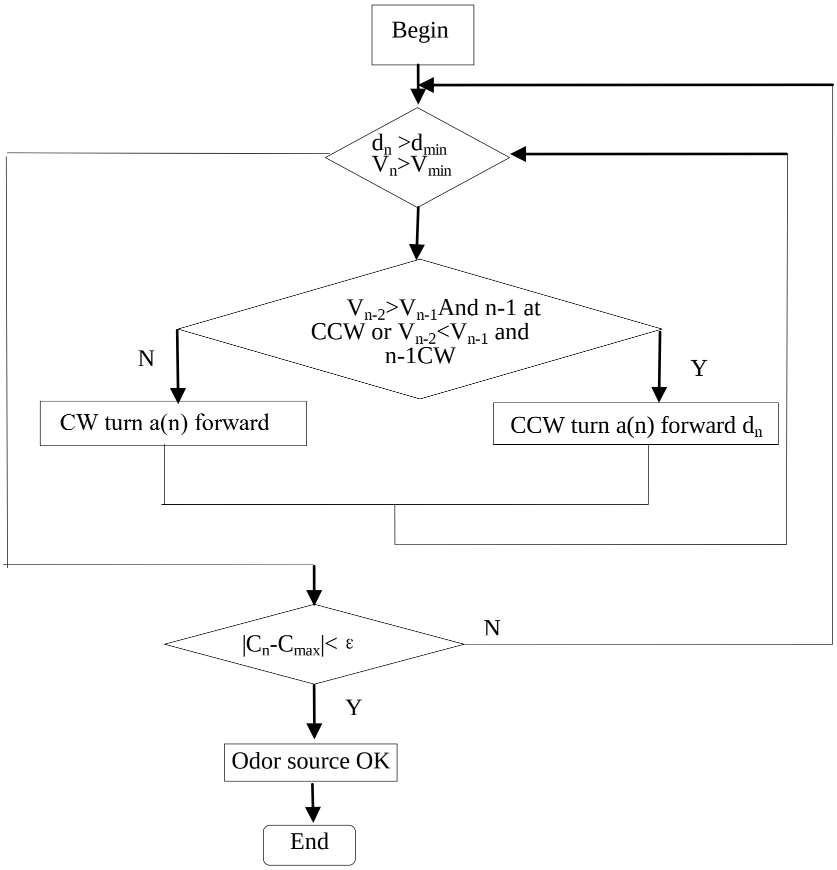


Figure 1 Olfaction searching module based on Bionic behavior

$$\alpha_n = \begin{cases} 1.1 & 0.8 \le |v_n| \\ 1 & 0.4 \le |v_n| < 0.8 \\ 0.9 & 0 \le |v_n| < 0.4 \end{cases} \tag{1}$$

$$k_d = \begin{cases} 1.1 & 0.8 \le |v_n| \\ 1 & 0.4 \le |v_n| < 0.8 \\ 0.9 & 0 \le |v_n| < 0.4 \end{cases} \tag{2}$$

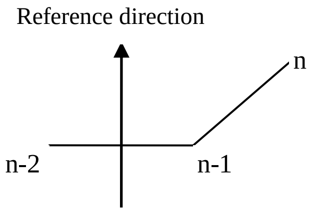


Figure 2 Estimating orientation principle based on tropotaxis

The algorithm's robot steps and corners vary in real time according to the rate of change of concentration. This strategy is very simple, does not pass the advanced intelligence strategy, does not depend on the wind direction, does not depend on the gas concentration value when searching, it avoids the disadvantage of the current gas sensor recovery time is too long, and improves the search efficiency of the robot.

3. Simulation Experiment

3.1 Experimental program designs

The experiment was conducted in a dynamic indoor environment. The gas leakage experimental environment was a square field with a length and a width of 10 m. The space occupied by the items such as the computer desk was removed, and the robot's range of activities was 8m8m, as shown in Figure 3. Smell leakage source instead of adding alcohol to the beverage bottle, a small inflator is used to quickly inflate the beverage bottle to simulate the source of the leak.

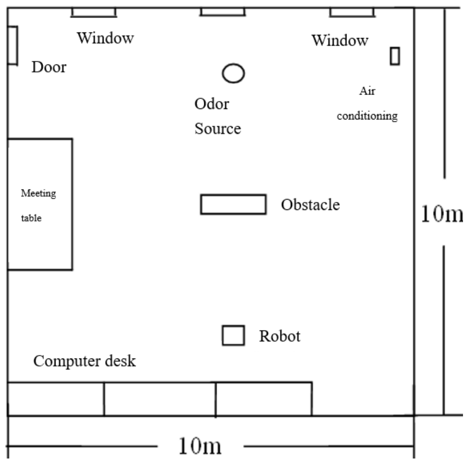


Figure 3 The schematic of experimental site

In the experiment, in order to detect the obstacle avoidance function in the robot's initiative olfactory strategy and whether the obstacle was mistakenly judged as the leak source, a cardboard box was added as an obstacle in the experimental site, the wind field of the site was in a natural state, the experimental gas concentration threshold from random to local search was set to 10 ppm. In order to test the reliability and stability of the initiative olfactory strategy, each experiment was performed 15 times.

3.2 Experiment platform

Experimental platform as shown in Figure 4, the multiple crawler-mounted mobile robot is composed of a crawler-type mobile robot body and a four freedoms anthropomorphic robot head system. The robot head has three-dimensional visual, auditory and olfactory sensory functions. The sensor detects the wind speed and direction in the experiment, providing wind direction and wind speed information for the initiative olfactory task.

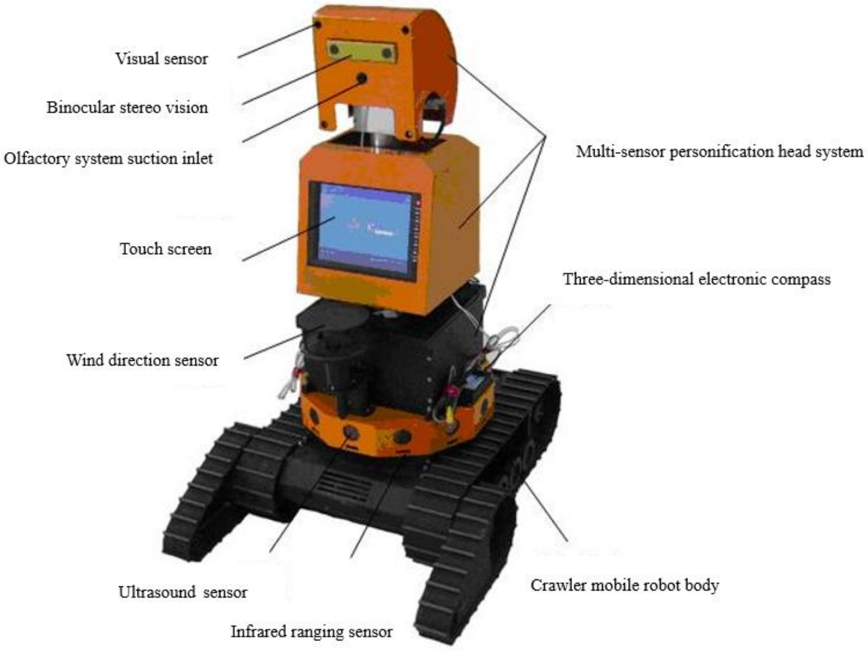
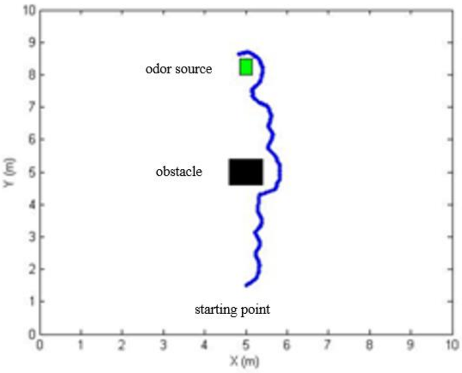


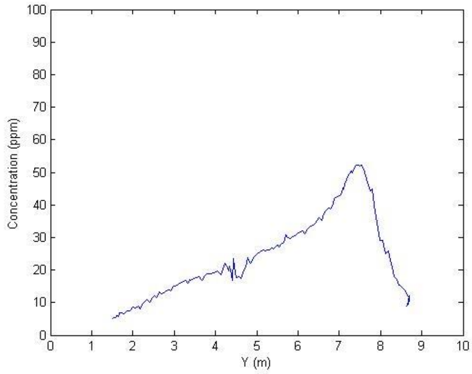
Figure 4 Multi-sense tracked mobile robot

3.3 Experimental process and results

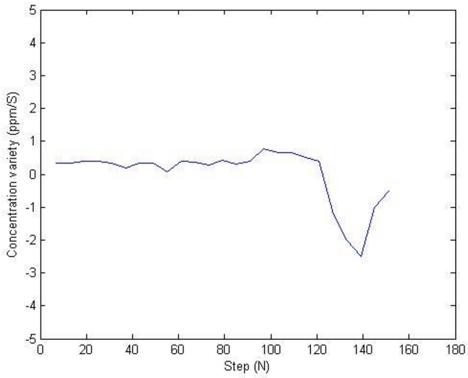
Based on the kinesis response and the phototactic behavior of the robot odor source localization strategy experiments first in a wind-free environment, in order to reduce the randomness of gas concentration changes, the concentration change rate of the weighted value of the six collected values, that is, each step sensor detects the relative concentration changes, the robot forward six steps based on the average rate of change as a basis for steering angle changes and step changes, and then the next step search. The beginning of the middle began, the experimental data is about 30 minutes in the simulation odor diffusion began. Robot search process need to avoid the obstacles set to reach the leakage source that is the odor source, obstacles placed point, the robot starting point, the odor source in a straight line. Figure 5 (a) shows the robot's overall search path. It can be seen from the figure that the robot search confirms the process of the odor source is divided into several stages. At the beginning, when the gas concentration information detected by the robot is lower than the set threshold, the random search of the initial step is executed and the search goes forward by a certain distance. After the robot detected the concentration information, the concentration increased, the absolute value of the rate of concentration change began to increase, the fluctuation was also large, and the robot search step and the angle began to change. When the vicinity of the obstacle is found, the concentration distribution of the leaked gas is complicated due to the presence of the obstacle. When the robot approaches the obstacle attachment, the concentration of the gas fluctuates greatly. When the robot detects the obstacle, as shown in Figure. 5 (b), when the robot is at a certain distance from the obstacle, the detected value of the concentration at this time is also the highest. The expert decision-making system based on the sensor information. The condition determining obstacle is a suspected taste source, the taste source determining module is started to determine whether the object is a taste source. After the robot crosses the obstacle, the detected gas concentration is higher than that before the obstacle, which is different from the condition for determining the odor source identification strategy , The robot determines the target is not the taste source, the robot goes to the implementation of the olfactory search module, the robot continues to smell the search until it reaches the vicinity of the taste, the robot will be the odor source as a suspected source, the implementation of the flavor determination module again, identify the conditions of the strategy, confirm that the suspected target is the source of the leak, stop the execution of the program, and the task ends. The concentration of gas collected during the robot search (Figure 5 (c)) and the rate of concentration change also validated the search process in accordance with the search algorithm and expert decision-making strategy design.



(a) Robot search trace



(b) The gas concentration collected by the robot



(c) Concentration rate of change

Figure 5 The searching path and collected gas concentration and variety of robot

3.4 Experiment analysis

According to the above experimental process, based on the kinesis response and tropotaxis robot odor source location strategy analysis, as shown in Table 1, this article from the following three aspects of strategy performance evaluation:

- Searching success rate

In the case of unsuccessful search, the robot failed to find a valid olfactory message clues when the odors began to diffuse for a short period of time (the robotic olfactory search experiment started almost simulating diffusion), trapped in the high-concentration area trap, the experimental set-time resulted in two more robots identifying the obstruction as odor source. This is turbulent because of turbulence near the obstacles, with the lowest nearby concentration being less than half the highest concentration, leading to miscarriage of justice.

- Searching efficiency

Robot search efficiency is the time it takes to complete the search task, here is the time the robot search to taste source. Due to inconsistent experimental conditions, such as site size, odor source, obstacle placement and robots search from different starting point, the completion time is not horizontal comparability and cannot be used as a measure of the efficiency of a strategy. Therefore, the ratio of the straight line distance to the leakage hole of the odor source and the total length of the path taken by the robot during the search process is taken as the search efficiency index of the robot's active olfactory strategy. From the search efficiency, it is relatively high, the robot can efficiently accomplish the odor source locating task.

- Average searching speed

The search speed of robots is the distance traveled by robots per unit time, which can reflect the rapid effectiveness of the robot's initiative olfactory strategy. In the data of Table 1, the numerator is the robot's average search distance and the denominator is the average search time, which means the average search speed of the robot in m/s.

Table 1 Performance analysis of odor source location strategy

Average success rate	Average search efficiency	Average search speed
13/15=0.86	6.5/8.46=0.77	8.46/51.8=0.163

4.Conclusion

Based on the kinesis response of flatworm and bio-tropotaxis bionic behavior of the flatfish, this paper designs orienting algorithm the odor source of a robot without depending on the absolute concentration of the odor and the information of the wind direction. Compared with the simulation, the robot's actual path is not particularly accurate, which is due to the accuracy of the robot walking, and the slipping of the crawler on the ground is an important factor. Experiments show that the algorithm is not affected by the wind direction and wind speed, and based on the rate of change of odor concentration to improve the search efficiency, has good stability and environmental adaptability, is a reliable active olfactory strategy, in the dark environment under extreme conditions of very low visibility, such as a fire, this strategy enables robots to work in extreme environments such as darkness, and odor smell tracking can be accomplished by detecting odor alone

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References

[1] PayneT L, BirchM C and KennedyC E J. Mechanisms in Insect Olfaction. *New York, USA: Oxford University Press*, 1986.
[2] HayesA T, Martinoli A and Goodman RM. Distributed odor source localization. *IEEE Sensors Journal* 2002,2(3): 260-271.
[3] Rozas R, Morales J and Vega D. Artificial smell detection for roboticnavigation. *Fifth International Conference on Advanced Robotics. Piscataway, NJ, USA: IEEE*, 1991. 1730-1733.
[4] LiSuxia. Research on locating gas leakage source By robot detection. *Experimental technology and management*. 2017,34(7):46-59.
[5] Chen Yicun. Time-variant method based on contaminant source localization active olfaction in indoor environment. *Journal of PIA University of Science and Technology (Natural Science Edition)*,2016,(03):257-263.
[6] Mohamed Awadalla,Tien-Fu Lu and Zhao F. Tian,Bassam Dally,Zhenzhang Liu. 3D framework combining CFD and MATLAB techniques for plume source localization research . *Building and Environment*. 2013, 70 (12): 1019.
[7] Tengfei Zhang, Hongzhu Li and Shugang Wang. Inversely tracking indoor airborne particles to locate their release sources . *Atmospheric Environment* . 2012, 55:328-338.

[8] Xiaojun Ma, Xiaoliang Shao, Xianting Li and Yiwei Lin. *An analytical expression for transient distribution of passive contaminant under steady flow field. Building and Environment* . 2011, 52 (6): 98-106.
[9] Zhiqiang (John) Zhai, Xiang Liu, Haidong Wang, Yuguo Li and Junjie Liu. Experimental verification of tracking algorithm for dynamically-releasing single indoor contaminant . *Building Simulation*. 2012, 5 (1): 5-14.
[10] Ishida H, Nakayama G and Nakamoto T, et al. Controlling a gas/Odor Plume-tracking robot based on transient responses of gas sensors J.*IEEE Sensors Journal* 2005, 5(3): 537-545.
[11] Pyk P, Bermúdez I Badia S and Bernardet U, et al. An artificial moth:Chemical source localization using a robot based neuronal model of moth optomotor anemotactic search. *Autonomous Robots*, 2006,20(3): 197-213.
[12] Marques L, Nunes U and DeAlmeida A T. Spread Nose: Distributed agents for environmental monitoring. *Proceedings of the International Workshop on New Developments on Sensors for EnvironmentalControl. Singapore: World Scientific Publishing*, 2003. 234-238.
[13] Loutfi A and Coradeschi S. Smell. Think and act: A cognitive robot discriminating odours. *Autonomous Robots*, 2006, 20(3): 239-249
[14] Lu Guang-da and Zhang Ming-lu. A Biological-inspired Gas/Odor Source Localization Strategy for Mobile Robot. *Journal of Hebei university of technologe*. 2010, 39(05):48-52.
[15] Frankel,G.S.and D.L.Gunn.The Orientation of Aniamals:Kineses,Taxes and Compass Reactions. *New York, Dover Publications Inc.1961.*
[16] FRANK W. GRASSO. Invertebrate-Inspired Sensory-Motor Systems and Autonomous, Olfactory-Guided Exploration.Biol.*Bull*.200(April 2001): 160–168.