

# Modified Simple Chemical Plume Tracing Algorithm

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**Abstract :** A simple chemical plume tracing algorithm has been modified and presented in this paper. This algorithm traces the plume based on maximum concentration of chemical/odor cues received by simulated omnidirectional gas sensors. Herein it is proposed to place the sensors in two different arrangements to facilitate the functioning of algorithm. These arrangements of sensors are namely, circular (rosette) type and rectangular, have been proposed to explore its effect on success rate of algorithm. A differential drive mobile robot has been considered around which these sensors are placed to trace the plume. Arena in which plume tracing algorithm has been implemented is a simulated environment based on time averaged Gaussian plume model. Variable wind conditions have been generated to validate the implementation of algorithm. In addition to success rate, number of steps taken to reach the source is taken as an underlying factor of performance measure.

**Keywords:** mobile robot; chemical plume tracing; omnidirectional sensors; chemotaxis; gaussian plume model

## 1. Introduction

Chemical plume tracing (CPT) has drawn the attention of scientific community in recent times. The solution to this problem can lead to major applications in the rescue operations in avalanche, looking for survivors in earthquake, finding drugs in customs and quarantine applications [1]. CPT is one of the important and intermediate stage of three subtasks namely plume finding, plume tracing and source declaration/identification. A lot of work has been reported on CPT compared to plume finding and source declaration [2].

Bio-inspired algorithms are well in practice to trace the plume up to its source. Such an attempt to localize underground odor source inspired by lower organism's behaviour looking for mates has been analysed. Method of accumulation of micro steps can improve the search efficiency and can further strengthen classical algorithms such as zigzag path and hexagon path algorithms [3]. E.coli, spiral and hexpath algorithms have also been verified experimentally with single robot and better results are reported. Their comparison is facilitated in indoor environments with no strong airflow [4]. Inspired by the behaviour of crab, lobster, moth or salmon in search of food or mating partners (analogous to source of odor), the CPT problem has been addressed in two stages. Initially with cross wind levy walk for plume finding and 'spiral' with 'surge' for plume tracing. It has been validated both in simulation and real world experiments [5].

On contrary to bio-inspired algorithms, gradient ascent techniques are also developed but less valued. A pair of gas sensors separated by some distance and mounted on a mobile robot is an example of active olfaction method. The measured concentration difference from two gas sensors can guide the heading of mobile robot to climb the concentration stairs gradually [6]. However there are efforts to use gas sensor arrays to tap the average concentration with increasing sample time [7]. Further there are no improvements in this technique which may have proved beneficial. In this paper, we present work on this grey area and explored the concentration information retrieval through arrangement of simulated gas sensors. Plume tracing algorithm proposed in our earlier work has been adopted [8, 9]. In this algorithm, array of gas sensors arrangement has been tested and validated through simulations.

This paper has been organized as section II gives detail about the simulation setup including environment, mobile robot, and implementation of algorithms. Section III is presented with results and discussions and last section is about conclusions.

## 2. Simulation setup

## 2.1 Simulation environment

To test the algorithm, simulated environment has been generated based on averaged time Gaussian plume model [10, 11]. Two types of environments have been considered with variation in wind velocity shown in Table 1. The mathematical expression for concentration 'c' of chemical gas at any point  $x = (x, y)$  in the domain of interest is given by:

$$c(x, \infty, x', y') = \frac{q_0 \exp\left(-\frac{v(d-x+x')^2}{2k}\right)}{2\pi kd} \quad (1)$$

Where ' $q_0$ ' is chemical release rate, ' $v$ ' is the wind velocity in positive direction of  $x$  co-ordinate, ' $d$ ' is Euclidean distance between the point source and the point of interest, ' $k$ ' is the diffusion coefficient and  $(x', y')$  are the coordinates of point source. Simulation environments have dimensions  $4m \times 4m$  bounded at its perimeter.

Table 1 Parameters for environment type I and II

Parameters	$v$	$k$	$q$	$x'$	$y'$
Type I	0.03m/s	0.003	0.5 mg/s	0.5 m	2.5 m
Type II	0.3m/s	0.003	0.5 mg/s	0.5 m	2.5 m

## 2.2 Plume tracing algorithm

In this paper a simple algorithm for plume tracing has been used with proposed arrangement of simulated odor/gas sensors around the body of virtual agent (VA), a differential drive mobile robot with circular base and a rigid body with non-deformable convention wheels [8][9]. In this algorithm all the simulated sensors provide the values of odor concentration, based on which maximum concentration is picked. VA guides its heading clockwise or anticlockwise in the direction of maximum concentration and takes a predefined step. For plume tracing, step size is fixed as 5 cm and for random search  $L_{\min}$  is taken as 1 cm [5]. Herein two types of arrangements are proposed for simulated gas sensors discussed below.

**2.2.1 Circular(rosette) arrangement and Rectangular arrangement** Sensors in circular rings has been kept around VA which resembles to rosette. Here 'M' denotes the no. of rings. There can be two or three circular rings. If the rings are two it is denoted by 'M2' and for three it is denoted by 'M3'. Also, the radial placement i.e. number of radial lines are denoted by 'N'. For e.g. If the number of radial lines is 7 it is denoted by 'N7' and likewise. It varies from N7 to N16. Fig. 1(a) and (b) shows circular arrangement for (M2, N7) and (M2, N16) respectively. Similarly, Fig. 1(c) and (d) shows circular arrangement for (M3, N7) and (M3, N16) respectively. Also, VA's body is surrounded by simulated sensors in rectangular arrangement. For a single ring (R1) it is shown in Fig. 1 (e) whereas for two rings (R2) it is shown in Fig. 1(f).

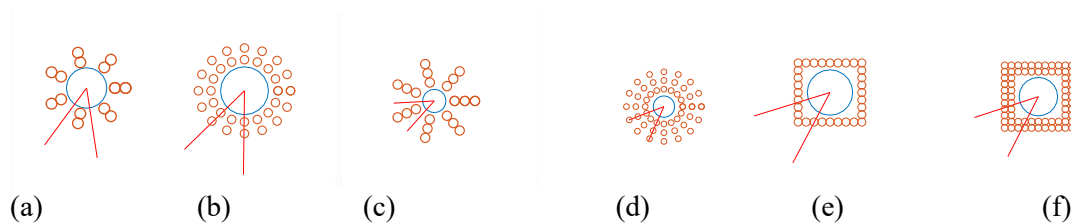


Fig 1. Arrangement of simulated sensors around VA

### 2.3. Outline of simulation experiments

There are two categories of experiments planned, first for the rosette arrangement and second for rectangular arrangement of simulated gas sensors. These sensors are assumed to give response without any delay. In each category no. of simulated sensors are increased by placing them in circular or rectangular arrangement with one or two rings encircling the virtual agent. For rosette arrangement apart from change in number of circular rings their radial arrangement has also been investigated. No. of radial lines have been increased, from seven to sixteen i.e. minimize the gap between sensors and increases the density in provided area. Also, we have tested the algorithm in two environments (type I and II) as discussed earlier in section II. There are 20 simulation experiments in each set of a category. For example, in case of rosettes  $N=7$  and  $M=2$  there are 20 simulation experiments. This belongs to set 1 hence increasing  $N=7$  to 16 makes 10 sets for  $M=2$ . In environment type I and II there are 20 sets each for rosettes. In environment type I and II there are 10 sets each for rectangular arrangement. Maximum allowed steps for VA to reach and declare source is 200. If the VA reaches close to the source less than 20 cm it means source has been declared. Similarly, no. of steps to reach the source for first time has been noted.

## 3. Results and Discussions

### 3.1. Environment type I

Success rate i.e. no. of simulation experiments in which VA reaches very close to the source has been presented here for both category I and II. Fig.2(a) shows the success rate for rosette arrangement of sensors, M2 and M3 with N7 to N16. It is observed that (M2, N7) success rate is 18. Also, for (M2, N10) success rate is 17. Similarly, for M=3 and N=7 and 16 is 18 and 17 respectively. Out of 20 simulation experiments, at least 17 or 18 no. of successful runs are there. In few cases only failure is encountered due to non-contact of VA towards edges of the plume. Not only on success rate, number of steps required to reach the source for the first time, taken into consideration.

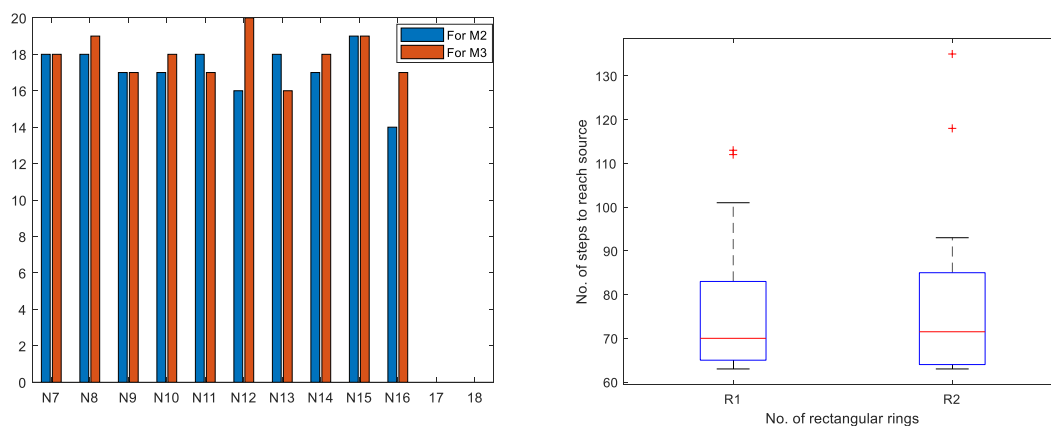


Fig. 2. (a)Success rate of rosette type arrangement of sensors (b)No. of steps to reach source (R1 and R2)

As far as rectangular arrangement is concerned for environment type I, 20 and 19 successful runs are observed for ring 1 and ring 2 respectively. Fig. 2(b) shows the box plot which depicts number of steps required to reach source in this case. For ring 1, minimum is 63 and maximum is 113 with median 70 and mean 77. For ring 2, minimum is 63 and maximum is 135 with median 71.5 and mean 78.6. Fig. 3 (a) shows boxplot for the number of steps to taken for each case of  $M=2$  and  $N=7$  to 16. The shortest of these needs 62 steps for  $M=2$  and  $N=15$  with median 79 and mean 89.20. Similarly, Fig. 3(b) shows boxplot for the number of steps to taken for each case of  $M=3$  and  $N=7$  to 16. Some combinations with lower no. of steps observed in  $M=3$  and  $N=7, 11$  and 16. For these minimum number of steps are 67, 73 and 68 respectively where maximum being 151, 122 and 171. Their medians are 85.5, 83 and 76 respectively. Corresponding mean is 91.7, 89.3 and 91.1. As compared to  $M=2$  and  $M=3$  takes more no. of steps with shortest being 62 for first case and 67 for second case.

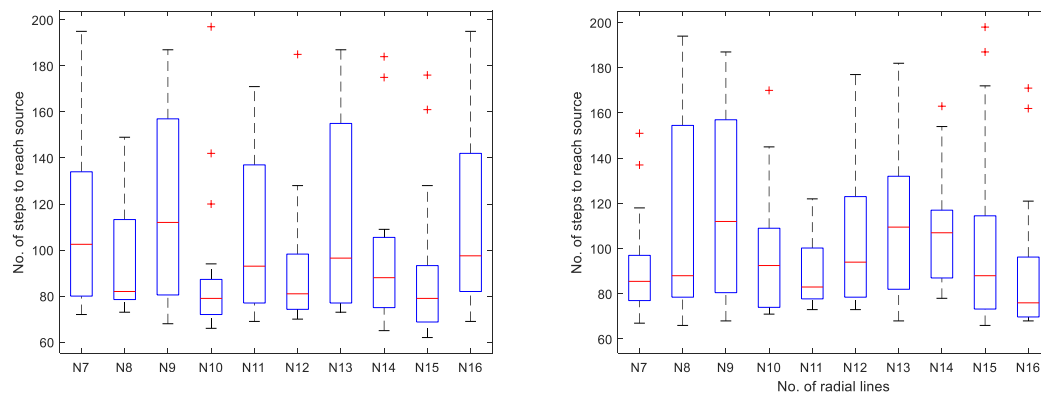


Fig.3 (a) No. of steps to reach source (M=2, N= 7 to 16) (b) No. of steps to reach source (M=3, N= 7 to 16)

### 3.2 Environment type II

For both categories success rate is poor. For rosette arrangement of sensors success rate is zero for  $M=2$  and  $M=3$  whereas for rectangular arrangement only one successful run is observed for ring 2 and zero for ring 1.

## 4. Conclusion

A simple chemical plume tracing algorithm has been adopted with proposed arrangement of omnidirectional simulated gas sensors. This algorithm is based on maximum concentration of odor/chemical cues to guide the heading of differential drive mobile robot. Step size is fixed for both plume finding and plume tracing algorithms. It is seen that in environment type I, more successful runs are there for rectangular arrangement efficiently reaching the source with less no. of steps as compared to rosette arrangement. Also, for rosette arrangement, for M2 successful runs are better than M3. For environment type II, all failures are there except for one in rectangular arrangement R2. This plume tracing algorithm will be supported by better random search algorithms to get in contact of plume which can improve success rate results.

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