Scope of Improvement in Algorithm for Odor Source Localization in an Indoor Dynamic Environment: A Preliminary Study

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***Abstract*—A study to explore possibilities to improve plume tracing algorithm in an indoor dynamic environment is reported in this work. It captures the success/failure of a differential drive mobile robot AKA Virtual Agent (VA) in localizing two sources of chemical emission with different intensities in an indoor environment. The plume tracing algorithm was tested under three different conditions. First, at an instantaneous sample point steady in time having information about plume concentration and wind airflow vectors and second in dynamic condition when each data point is sampled at a constant rate of 1 sample/sec. We have also investigated a pseudo steady state situation, keeping the environment dynamic but retained the sampled data for some duration i.e. 1 sample/n sec (1<n<20) which can facilitate more decision making capability of mobile robot and in turn more random turn angles and move lengths. Results have been compiled based on above three conditions and reveal that only a limited instantaneous sample data points give 100 % success and thereafter it reduces to minimum for others, whereas for dynamic (1 sample/sec) gives minimum success runs and lastly for third case it is moderate.**

***Index Terms*—indoor, dynamic environment, odor source localization, plume tracing algorithm, chemotaxis, mobile robot**

I. Introduction

An act of finding the source of chemical emission and further declaring it in an environment is odor source localization. It basically consists of three subtasks viz. plume finding, plume traversal and source identification. This research has gained momentum in recent years only to provide scientific community with better methods/procedures to find a solution [1]. It has drawn much interest of scientific community and their approach to solve this problem is diverse whether it is bio-inspired, map based, probabilistic or formation based. But prior to this as literature suggests researchers have chosen different environmental conditions to test and validate their scientific approach. Recently [2] published research article on underground source localization based on a variation of lower organism search behavior. In similar environment again, inspired by lower organism behavior idea of olfaction threshold based thought of micro-steps accumulation was proposed by [3] for odor search. Not much earlier [4] used moth inspired chemical plume tracing strategy on an autonomous underwater vehicle. In contrast to this a lot of literature [5] is available on source localization for the cases above ground in advected and diffusive environments. [6] proposed a strategy for performing an efficient autonomous search to find an emitting source of unknown strength, releasing particles into the atmosphere driven by turbulence causing irregular gradients and intermittent patches. [7] designed a bio-inspired 3D algorithm for odor search in realistic environmental conditions. This clearly indicates that various approach has been adopted to solve this problem in different environments. We are motivated on this aspect and concerned about feasibility of an algorithm in different environments. A preliminary work has been outlined in sections below that highlights hidden reasons for failure of an algorithm and widens scope of improvement.

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II. Simulation Setup

A. Plume Data

The CFD simulations data used in this work is available in public domain [8] and used before by authors [9]. It contains information of airflow vectors, plume/gas/odor concentrations at different nodes in a mesh generated by [10]. The overall size of the arena is 26 m (meters) in X direction and 25 m (meters) in the Y direction. The distance measured in units presented using X-Y coordinate can be converted to mm using the scale 1:39.4 in the X direction and 1:39.6 in the Y direction. There are two source of emissions, marked source 1 (S1) and source 2 (S2) in Fig. 1. As per CFD data generated emission intensity of source 1 is greater than source 2 and latter is considered secondary source. Black arrows shows the direction of airflow in the building.

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Figure 1. Start position of simulated robot marked 'A' alphabetically

The full setup and a detailed description of the simulation framework for plume tracing research by integrating CFD simulations and MATLAB are described in original publication [11].

B. Simulated Robot

The simulated robot AKA virtual agent (VA) used in this paper is a differential drive robot with two wheels and having a circular base of diameter 31.6 cm shown in Fig. 2. It has two collision avoidance distance sensors in front placed apart at an angle of 90°. The MATLAB code used in this paper for developing the simulated mobile robot was based on [12]. The kinematics model was extracted from [13].

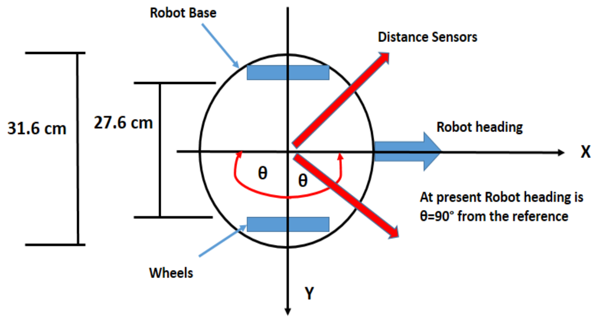

Figure 2. Dimensions and description of the virtual agent (VA)

C. Software and Hardware Platform

All the simulations have been performed in MATLAB R2018a mathematical software package (Mathworks Inc.) with a personal computer having an Intel(R) Core(TM) i5-3230M CPU@2.6GHz with 4 GB RAM. Simulated results have been generated and compiled in MATLAB only.

D. Plume Tracing Algorithm

Here we have implemented a simple plume tracing algorithm which is also called max-algorithm hereafter. In this algorithm a meshgrid was created in simulation with mobile robot body at the center shown in Fig. 3. An enlarged illustration is shown in Fig. 4. This meshgrid is 17×17 points in dimensions i.e. in total 289 points. It is assumed similar to an array of gas sensor where each point resembles to a gas sensor node. At a time VA receives gas concentration information from 289 simulated gas sensor nodes and finds the node with maximum concentration. Span of simulated gas sensor nodes with dimensions are shown in Fig. 5. In real life situations these sensor arrays are assumed to be kept on robot body and extend up to 16 cms along two mutually perpendicular directions in horizontal plane. The current robot heading is aligned in the direction of the coordinate (X, Y) at which the maximum concentration of the odor/gas concentration was found. Same algorithm is adopted in recent works [9].

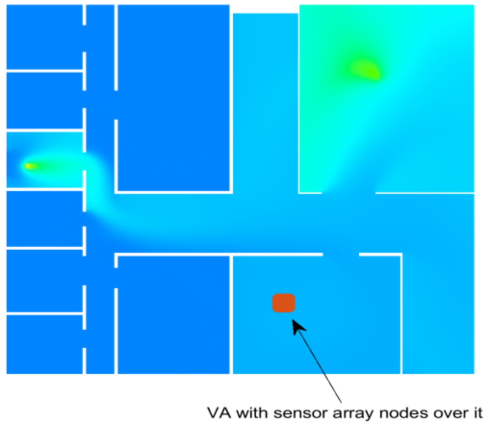

Figure 3. VA moving with gas sensor arrays placed over VA

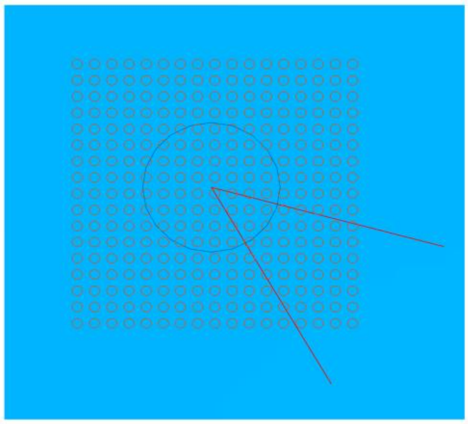

Figure 4. Enlarged figure showing simulated omnidirectional gas sensor arrays placed over VA

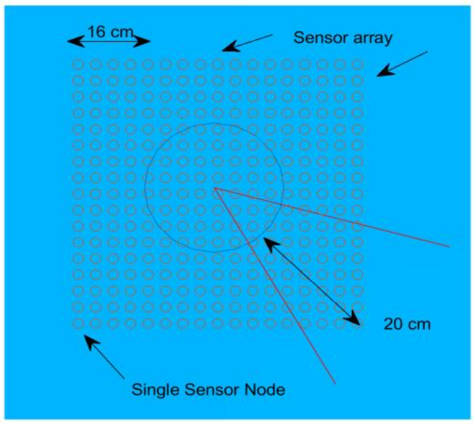

Figure 5. Dimensional information of omnidirectional gas sensor arrays with VA at the centre

First of all it checks for the difference between the current robot heading and the heading at which it has to be aligned and then it rotates the simulated robot on its own axis clockwise or anticlockwise depending on the difference is positive or negative accordingly. Further it checks for the obstacles nearby and progresses towards the coordinate of maximum concentration avoiding obstacles with wheel speed v=10 cm/s. Pseudo code for the same has been furnished in the Table I.

TABLE I. PLUME TRACING ALGORITHM

```
Initialization;
1:   Δθ ← Difference between current robot heading
     and the angle at which coordinates of maximum
     odor/gas concentration are located
2:  if (Δθ ≤ 0) then
3:      rotate anticlockwise
4:      update robot heading
5:      drive to safe distance avoiding obstacle in the
        direction of updated robot heading in step (4)
6: else
7:      rotate clockwise
8:      update robot heading
9       drive to safe distance avoiding obstacle in the
        direction of updated robot heading in step (8)
10:   end if
11:  return updated position
```

III. RESULTS AND DISCUSSIONS

A. Test Condition 1

Plume data (gas concentration and airflow vectors) procured has realistic transient wind and plume propagations and distributions. These are produced at different time steps with one second increments. Therefore total 800 sample points were stored in different file formats. In the first experiment test runs were conducted (to localize source S1) on each sample and for the whole run the sample remains same that means it is a steady state condition. Each experiment on a sample records success/failure for 100 runs. Here with successful run means VA had reached the source and declared it successfully. It can be noted that VA starts its search operation from the same point marked alphabetically 'A' in Fig. 1. After completion of simulation runs it was observed that only for few samples, 100 % success was achieved and for others it was almost none. Variation of wind strength near source 1 (S1) has been plotted and shown in Fig. 6. Similarly variation in source intensity (at S1) is plotted and shown in Fig 7. Analysis shows that variation in both wind strength and source intensity is sinusoidal in nature with time. Hence samples on which 100 % success has been recorded is marked as 'zone of success' in Fig. 6. And Fig. 7 respectively. This trend is periodic and it continues for other samples too as identified in Fig. 6 and 7 below. Details about success rate are available in Table II. As far as other sample points are concerned in those cases VA gets stuck in a local region and exits the process after few steps.

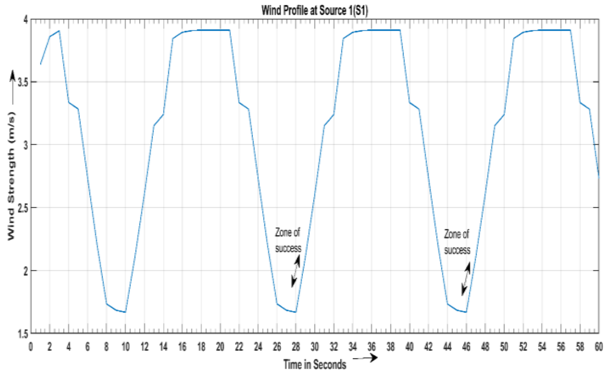

Figure 6. Wind profile at Source S1

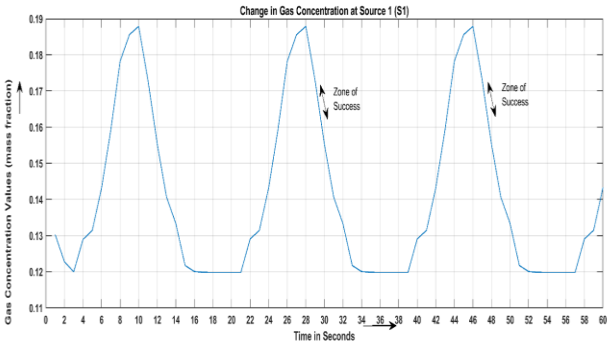

Figure 7. Source profile at Source S1

It is evident from Table II that on samples such as 28, 29 and 30 which was produced at 28th, 29th and 30th second of data generation has specific characteristics about wind strength and source intensity at source 1. In all these types of samples wind strength at S1 increases whereas source intensity at S1 decreases. This condition must have produced enough defined gradients inside arena to help the VA decide and surge accordingly.

TABLE II. NO. OF SUCCESSFUL RUNS FOR TEST CONDITION 1

Sample data	No. of successful runs	Wind profile at S1	Source profile at S1
28,29 & 30	100	Strength increases	Intensity decreases
46,47&48	100	Strength increases	Intensity decreases
66,67&68	100	Strength increases	Intensity decreases
84,85&86	100	Strength increases	Intensity decreases

B. Test Condition 2

In this case data is being sampled at a constant rate of 1 sample/sec and can be referred as dynamic/transient conditions. Successful runs out of 100 simulations have been compiled and shown in Table III below for S1 and S2. It can be inferred that for S1 and S2 no. of successful runs are nil except for wheel speed 4.5v and 6v. Indeed for dynamic conditions successful runs are at cost and it needs quite attention to improve the plume tracing algorithm. Little improvement has been observed when surge distance increases in turn increasing wheel speed. But 6v is high (60 cm/s) considering indoor environment.

TABLE III. NO. OF SUCCESSFUL RUNS FOR TEST CONDITION 2

Source	Manoeuvre speed of VA								
	1v	1.5v	2v	2.5v	3v	3.5v	4v	4.5v	6v
S1	0	0	0	0	0	0	0	0	6
S2	0	0	0	0	0	0	0	3	14

C. *Test Condition 3*

This section is a hypothetical situation in which a sample was retained for some duration to take decisions unless and until time gets consumed in taking five or six steps but before that we explain the concept of surge distance and turn angles used in this condition.

D. *Random Turn Angel and Surge Distance*

In this subsection we try to explain the importance of number of steps with varied surge distances and random turn angles. There are total 800 sample data of gas concentrations which is sampled at a constant rate of 1 sample/sec. But VA in this test condition doesn't decide its single step after each sample rather takes multiple steps based on a single sample information. This particular sample is retained as long as VA takes multiples steps with random turn angles creating a pseudo static state. This is completion of one iteration but in parallel data run goes on at a constant rate with time interval of 1 sec. So let us assume that 'p' sample is available at present, therefore after one iteration next sample will be 'p+q' where 'q' is the time elapsed in one iteration. Surge distance is proportional to the distance between its current position and the gas point node of maximum concentration. The same sample sustains when it take two steps, three steps etc. and after each step it has steady information about maximum concentration. Fig. 8 shows an instance when VA took six steps with different surge distances and turn angles (at speed 4.5 v). Hence one iteration may consist one step, two step and maximum six steps. Another Fig. 9 shows when VA took five steps in similar fashion.

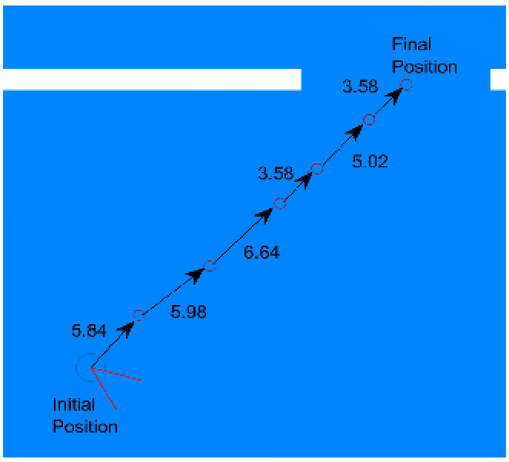

Figure 8. Surge distance with six steps having random move length (cm) in each step

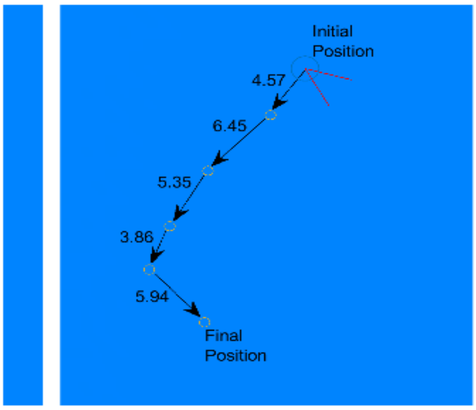

Figure 9. Surge distance with five steps having random move length (cm) in each step

E. *Success Runs in This Condition*

So most successful runs are observed when steps are five and six and also wheel speed is considerably higher as shown in Table IV. A slight difference in successful runs for S1 and S2 is there because latter is situated at half of the distance of S1. Hence more no. of successful runs even at lower wheel speeds for S2 but it is compulsory to have higher wheel speeds such as 4v or 4.5v with no. of steps five or six to reach and declare S1. Some results are presented related to successful tracing and declaration of S1 at speed 4.5v with no. of steps five and six. Box plots in Fig. 10 and Fig. 11 gives information about variation in surge distance and time elapsed in each successful run at wheel speed 4.5v with six steps. In similar lines Fig. 12 and Fig. 13 gives same type of information at wheel speed 4.5v but with five steps. It can be observed that surge distance are comparatively higher for 4.5v with six steps than 4.5v with five steps. Also correspondingly time consumed is more for 4.5v with six steps than 4.5v with five steps. It can be observed that no. of successful runs have increased as compared to test condition 2 which was dynamic and data sampling was 1 sample/sec. In this hypothetical case as stated earlier sample is retained for some duration i.e. 1 sample/n sec where 1<n<20. It gives ample time to VA for decision making and results in moderate performance but not better than test condition 1.

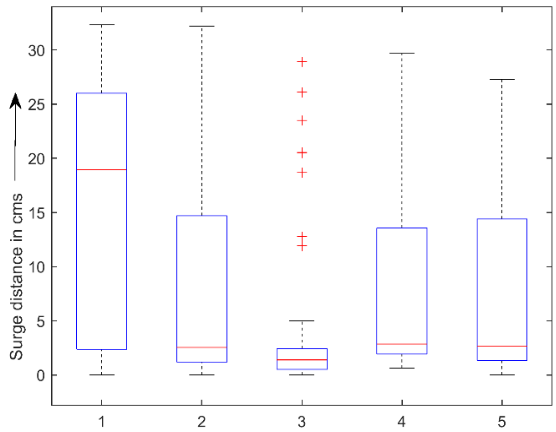

Figure 10. Variation in surge distance in cms in five successful runs for S1 (wheel Speed 4.5v with six steps)

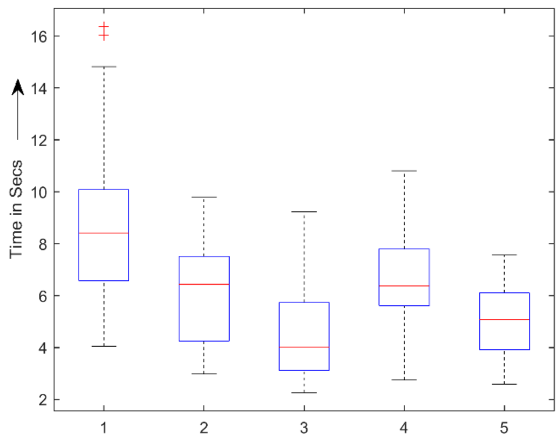

Figure 11. Variation in time consumed in five successful runs for S1 (wheel Speed 4.5v with six steps)

TABLE IV. NO. OF SUCCESSFUL RUNS FOR TEST CONDITION 3

Source	Manoeuvre speed of VA							
	1v	1.5v	2v	2.5v	3v	3.5v	4v	4.5v
S1 (Five steps)	0	0	0	1	2	1	2	6
S1 (Six steps)	0	0	0	0	4	3	7	5
S2 (Five steps)	5	13	46	44	44	43	41	25
S2 (Six steps)	8	0	33	40	43	31	55	47

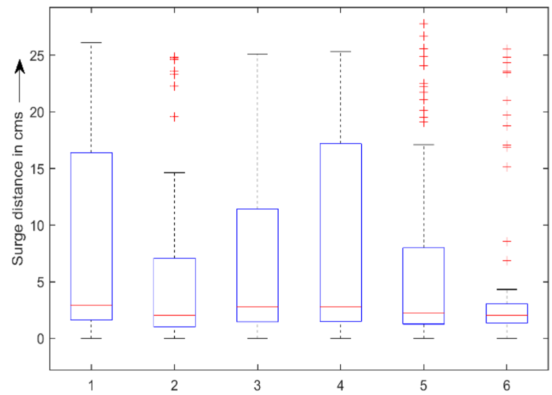

Figure 12. Variation in surge distance in cms for six successful runs for S1 (wheel Speed 4.5v with five steps)

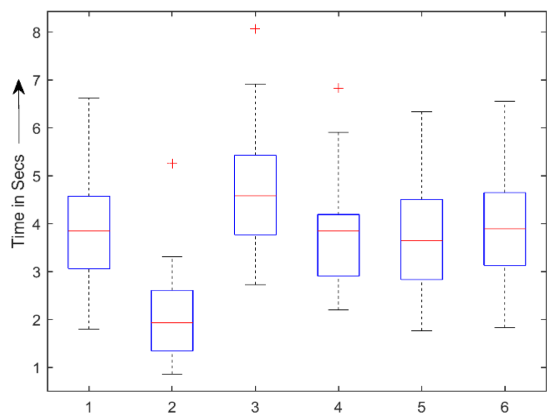

Figure 13. Variation in time consumed for six successful runs for S1 (wheel Speed 4.5v with five steps)

IV. CONCLUSION

Through this paper it has been attempted to explore suitability of an algorithm to work in an indoor dynamic environment. Its test in this condition (1 sample/sec) does not yield good results unless and until surge distances are increased. In contrast, tests in static conditions shows there are only few valid data points which provides well defined gradient and others make the VA confused and lost. This calls for appropriate modifications in the plume tracing algorithm so that it can succeed on other instantaneous data points too. As a result it will ensure success during dynamic conditions also. The experiments during the pseudo steady conditions, where the sample was retained for some duration, shows that increasing number of steps and wheel speed (in turn surge distance) increases success rate. Based on the numerical experiments it can be concluded that the algorithm works well for static conditions. However, for applications in dynamic environment further improvement is required. For example including information of wind strength with direction vectors. Moreover array sensor size or more gas sensor nodes can be employed to get the plume information from omnidirectional regions and hence affecting success rate overall. Therefore, success of an algorithm in steady environment is no proof for its validity under dynamic environment. Accordingly, further work is under progress to verify the success at all the instantaneous data points in time and then check its validity in dynamic environment.

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REFERENCES

[1] N. L. Husni, A. Silvia, S. Nurmaini, and I. Yani, "Odor localization sub tasks: A survey," *Journal of Telecommunication, Electronic and Computer Engineering*, vol. 8, pp. 101-105, 2016.

[2] Z. Chen and J. Wang, "Underground odor source localization based on a variation of lower organism search behavior," *IEEE Sensors Journal*, vol. 17, pp. 5963-5970, 2017.

[3] J. Wang, Z. Chen, and Z. Lei, "Olfaction threshold-based thought of micro-steps accumulation and its application on odor source search," *IEEE Sensors Journal*, vol. 18, pp. 7294-7304, 2018.

[4] W. Li, J. A. Farrell, S. Pang, and R. M. Arrieta, "Moth-inspired chemical plume tracing on an autonomous underwater vehicle," *IEEE Transactions on Robotics*, vol. 22, pp. 292-307, 2006.

[5] G. Kowadlo and R. A. Russell, "Robot odor localization: A taxonomy and survey," *The International Journal of Robotics Research*, vol. 27, pp. 869-894, 2008.

[6] M. Hutchinson, H. Oh, and W. H. Chen, "Entrotaxis as a strategy for autonomous search and source reconstruction in turbulent conditions," *Information Fusion*, vol. 42, pp. 179-189, 2018.

[7] F. Rahbar, A. Marjovi, P. Kibleur, and A. Martinoli, "A 3-D bio-inspired odor source localization and its validation in realistic environmental conditions," in *Proc. IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2017, pp. 3983-3989.

[8] T. F. Lu, "Indoor odour source localisation using robot: Initial location and surge distance matter?" *Robotics and Autonomous Systems*, vol. 61, pp. 637-647, 2013.

[9] R. K. K. Gaurav, A. Kumar, and A. P Bhondekar, "Exploring robot behavior in search of a chemical source," in *Proc.*

International Conference on Intelligent Autonomous Systems, Singapore, March 1-3, 2018, pp. 142-145.
[10] Z. Liu and T. F. Lu, "A simulation framework for plume-tracing research," in *Proc. Australasian Conference on Robotics and* Automation, 2008.
[11] M. Awadalla, T. F. Lu, Z. F. Tian, B. Dally, and Z. Liu, "3D framework combining CFD and MATLAB techniques for plume source localization research," *Building and Environment*, vol. 70, pp. 10-19, 2013.
[12] S. Lankton. Robot simulator. [Online]. Available: https://ww2.mathworks.cn/matlabcentral/fileexchange/15803-robot-simulator
[13] G. W. Lucas. (2001). A tutorial and elementary trajectory model for the differential steering system of robot wheel actuators. [Online]. Available: rossum.sourceforge.net/papers/DiffSteer/DiffSteer.html

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