# Gas Source Localization Using an Olfactory Mobile Robot Equipped With Wind Direction Sensor

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***Abstract*—Searching for locations of dangerous, explosive, and flammable gas sources by human can endanger health and even lives. Therefore, the use of robots is needed in this situation. This paper discusses the gas source localization using an olfactory mobile robot equipped with two gas sensors to navigate the robot and three anemometers to determine wind direction. The Intel Curie module is used as a microcontroller that handles all electronic compartments to obtain sensor signals, and robot movements. The experimental results show that the addition of a wind direction sensor can improve the robot's ability to find a gas source, in which the robot does not lose track of the odor plume in a turbulent air.**

***Keywords—gas source localization, olfactory mobile robot, wind direction sensor.***

## I. INTRODUCTION

Gas is an important aspect of life not only used for respiration, but also as a source of energy and industrial materials. Besides being useful, there are also dangerous properties of gases such as toxic, flammable, and explosive. Some accidents have occurred that involve dangerous gases [1], [2]. The search for the location of gas sources by humans is very risky. For such dangerous tasks, the use of mobile robots is an appropriate alternative method [3]. The electronic nose system integrated in the mobile robot can help to search for gas sources [4]-[9].

Several methods are used to track the odor plume in turbulent conditions [10]. However, this method often loses the odor plume because there is no information about wind, as shown in Fig. 1. Therefore, a mobile robot to find gas sources in the outdoor environment must be equipped with wind direction sensors [11], [12].

The nature of a gas is to spread and fill throughout the room. In open air, the gas moves from one point to another by the wind movement (advection). Every time the gas moves, there will be a decrease in the concentration of the gas molecule because the particles will move from the high concentration to the low concentration (diffusion) until equilibrium is reached. Gas can spread to the surrounding air with different concentrations depending on the distance from the source. The wind has an important role in gas movement by advection and diffusion, which can cause the odor plume to spread in the room [13] - [15].

The method for searching the gas source location usually consists of three steps, i.e. finding the odor plume, tracking the plume, and declaration of the finding. In the previous study, a mobile robot is used to find a gas source with an 80% success rate in simulations [11]. A mobile robot to search for a gas source is equipped with four anemometers consisting of hot wires wrapped around the temperature sensor used to determine the wind direction [12]. The sensor requires complicated calibration because it must regulate the temperature for all four hot wires that depend on the length of the wire and the constant current source. This causes the detection of wind direction to have low accuracy; therefore, the mobile robot takes a long time to find the source of the gas.

In this study, we have developed an olfactory mobile robot equipped with gas sensors and wind direction sensor to find gas source. The wind direction in this study is measured by using Wind RevP anemometers based on the positive temperature coefficient of the thermistor. This device is capable of measuring wind speeds from 0 to 150 mph with an accuracy of 0.5 mph. This wind direction sensor can increase the success rate of robot to find gas source and maintain the robot navigation to remain in the plume odor especially in turbulent air.

## II. METHOD

### A. The Olfactory Mobile Robot

The system consists of a differential steering mobile robot equipped with ultrasonic proximity sensors, wind speed sensor based on Wind RevP thermal anemometers, TGS 2610 gas sensors, and Intel Curie module. The Intel Curie module is a hardware product contains two small processor cores, an x86 (Quark) and a 32-bit ARC core architecture clocked at 32 MHz. The microcontroller board is equipped with 14 digital input/output pins in which 4 pins can be used as PWM outputs, 6 pins as analog inputs, USB connector for serial communication and sketch uploading, 196 kb flash memory, 24 kb SRAM, ICSP headers with SPI signal and $I^2C$ dedicated pins. The robot platform used for the experiment is shown in Fig. 2.

### B. TGS 2610 Gas Sensor

There are several types of gas sensors, namely metal oxide semiconductor (MOS), electrochemical cell, conducting polymer, quartz microbalance, surface acoustic wave, and photo ionization detector [16]. In this study, the MOS type gas sensor was chosen because of its advantages in fast response and robust. This sensor is also very sensitive to changes in several parts per million [17]. This sensor works based on chemical reactions such as sensor resistance depending on the concentration of gas absorbed on its surface. The higher the gas concentration, the lower the sensor resistance is.

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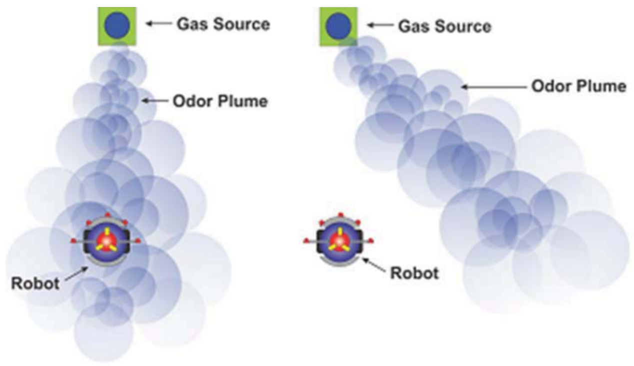



(a) (b)

Fig. 1. Gas source localization with a single robot in: (a) stable air, and (b) windy air.

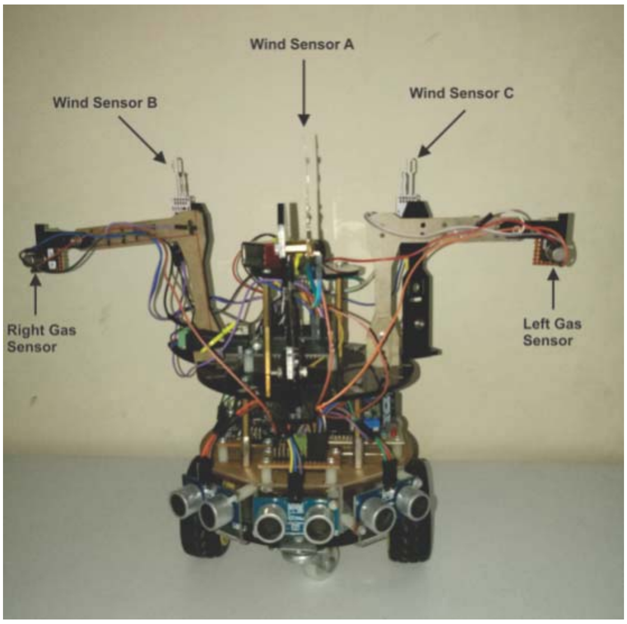



Fig. 2. The olfactory mobile robot used for the experiments.

The relationship between the sensor resistance (R) and the gas concentration (C) can be expressed as:

$$R = A[C]^{-\alpha} \tag{1}$$

where A is gas response coefficient, and α is the sensitivity.

TGS 2610 gas sensor has high sensitivity to propane and butane, making it ideal for liquefied petroleum gas (LPG) monitoring [18]. The sensitivity characteristics and basic measuring circuit are shown in Fig. 3, with the load voltage of $V_{RL}$ is expressed as:

$$V_{RL} = \frac{R_L}{R_S+R_L} V_C \tag{2}$$

## C. Gas Distribution

Advection is the movement of gas from one point to another due to the wind, while diffusion is the movement of gas molecules from highly to less concentrated areas. This occurs because of not only diffusion concentration gradients, but also differentiation of pressure, temperature, or external force fields. Fig. 4 shows the movement of homogeneous gases by decreasing the concentration and spread of gases in the air expressed as:

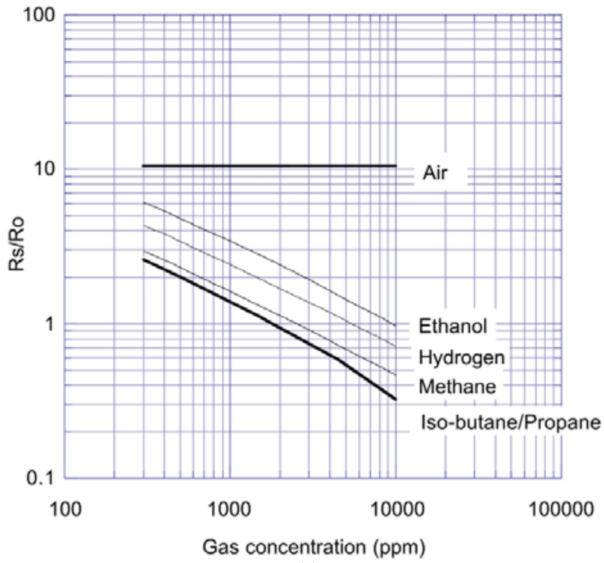
$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} = D\frac{\partial^2 c}{\partial x^2} \tag{3}$$

where *C* is the gas concentration, *D* is diffusion coefficient, *u* is flow speed, t is time, and x is position. The concentration of the gas at t = 0 is expressed as:

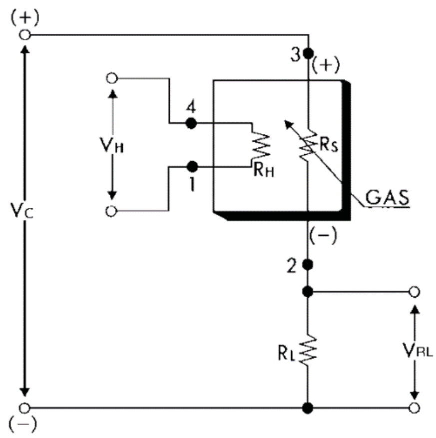
$$C(x) = M\delta(x) \quad (at\ t = 0) \tag{4}$$

where C(x) is initial gas concentration, M is mass, and δ (x) is Dirac delta function. On the other hand, the gas concentration at t ≠ 0 can be expressed as:

$$C(x,t) = \frac{M}{A_{yz}\sqrt{4\pi Dt}} exp\left(\frac{-(x-ut)^2}{4Dt}\right) \tag{5}$$




(a)




(b)

Fig. 3. TGS 2610 gas sensor: (a) the sensitivity characteristics, and (b) the basic measuring circuit.

## D. Wind Direction Sensor

To determine the direction of mass transfer of gas, an equipment that can predict wind direction is needed. The wind direction sensor consists of three thermal anemometers located at every 120 degrees, as shown in Figure 5. The transducer will produce internal heating that is equivalent to the environment [19], [20]. The amount of input power is expressed as:

$$I^2 R_W = h.A_W(T_W - T_f) \tag{6}$$

Where $I$ is the input current, $R_w$ is the resistance, $h$ is the heat transfer coefficient, $A_w$ is the surface area, $T_w$ is the transducer temperature, $T_f$ is the air temperature.

$$\mathrm{R_W} = \mathrm{R_{Ref}}[1 + \alpha\,(\mathrm{T_W} - \mathrm{T_{Ref}})] \tag{7}$$

where α is the coefficient of thermal, $T_{Ref}$ is the reference temperature, and $R_{Ref}$ is the resistance at the reference temperature [21].

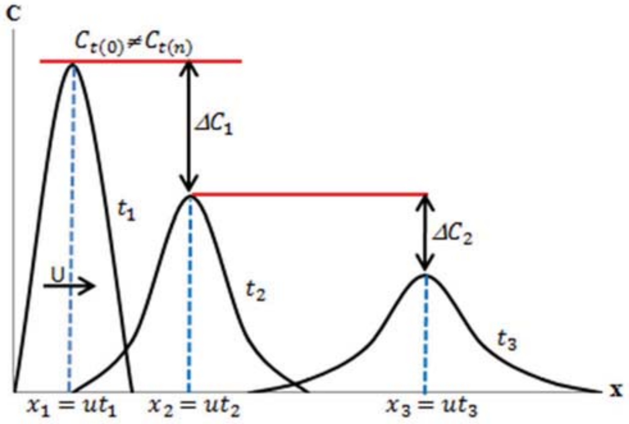



Fig. 4. The advection-diffusion gas distribution.

The wind direction in this study was measured by using Wind RevP from a modern device based on a positive coefficient temperature thermistor. Analog data from Wind RevP is converted into digital data using an internal analog to digital converter in the microcontroller module. The data is then processed into wind speeds in miles per hour (mph).

*E. Navigation Algorithm*

Fig. 6 shows the navigation algorithm of the olfactory mobile robot. The robot moves forward if the two gas sensors detect the same gas concentration and the wind direction is detected from the front. The robot moves to the right if the right gas sensor detects more gas concentration than the left gas sensor and the wind direction is detected from the right, and vice versa.

## III. Results and Discussion

The initial experiment is to measure the wind speed by using three Wind Rev P anemometers located at 50 cm, 100 cm, and 150 cm from the fan. The experimental results show that the wind speed decreases with respect to the distance of the wind source, as shown in Fig. 7. The next experiment is carried out using three TGS 2610 gas sensors located at 50 cm, 100 cm and 150 cm. Butane gas is sprayed at a wind speed of 6 mph, and then the data of each sensor is recorded for each concentration of gas entering through the three sensors, as shown in Fig. 8. This depicts the characteristics of mass transfer of butane gas propagated in the process of advection and diffusion in the open air.

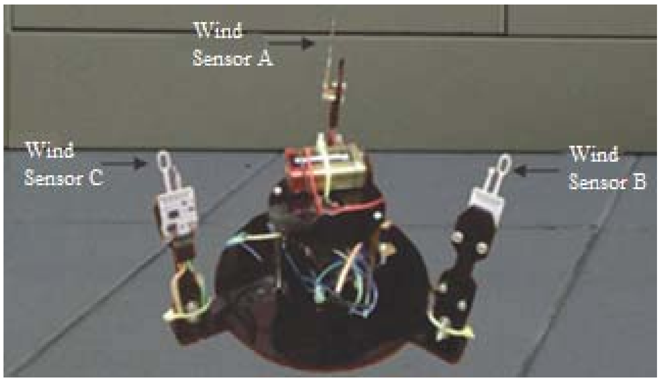



Fig. 5. The wind direction sensor.

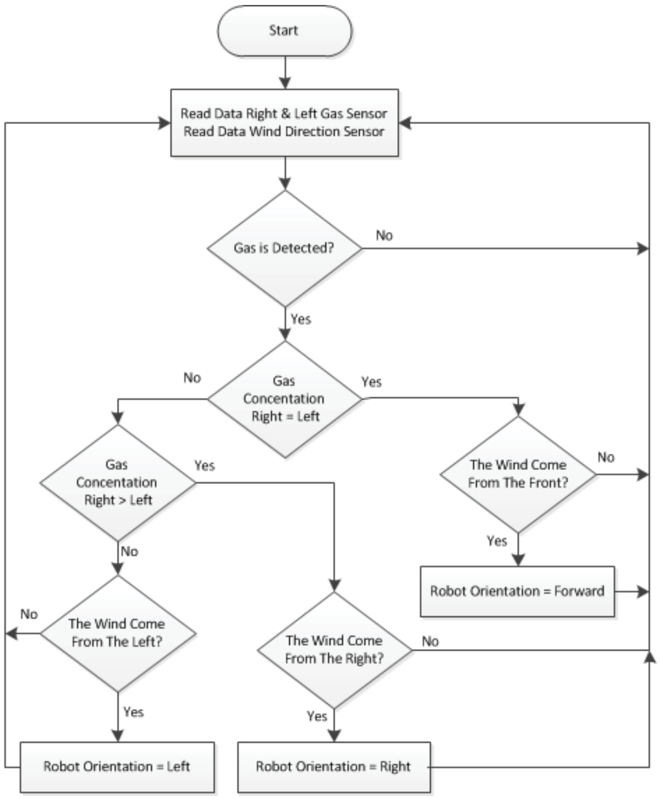



Fig. 6. The navigation algorithm.

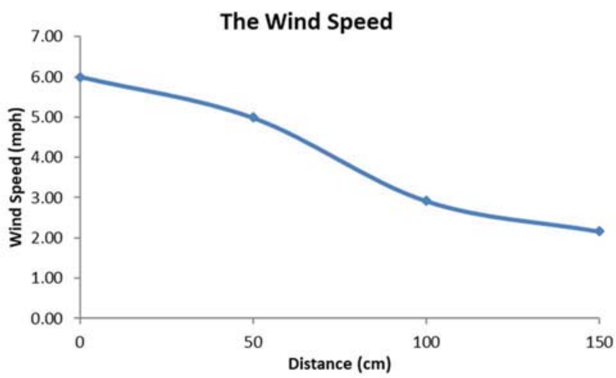



Fig. 7. The wind speed to the source distance.

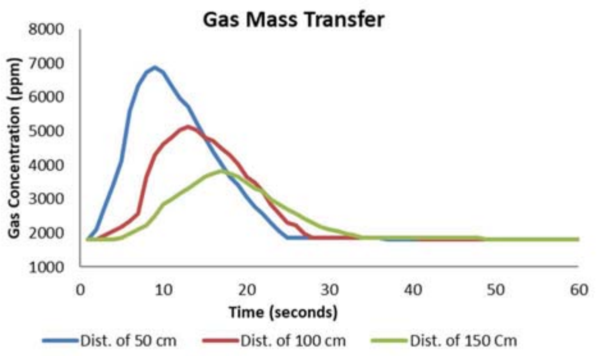



Fig. 8. The mass transfer of butane gas to various gas source distances.

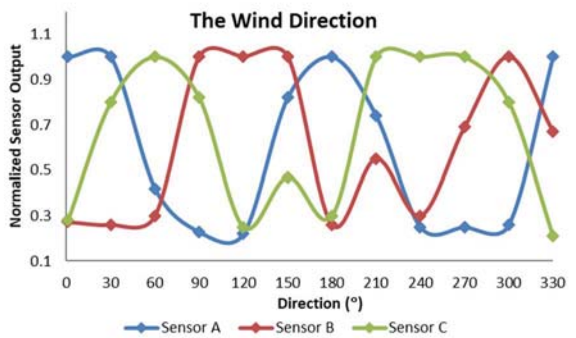



Fig. 9. The wind direction patterns.

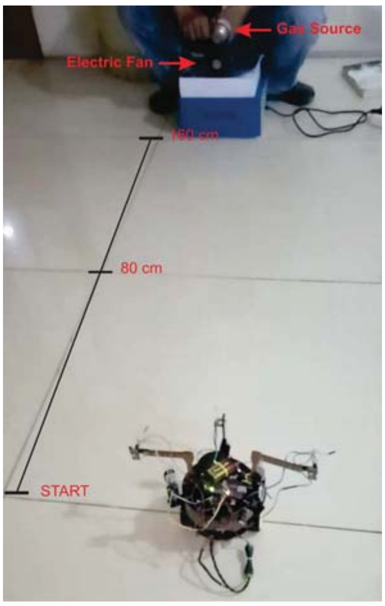



Fig. 10. Gas localization testing by mobile robot

The normalized response of each anemometer to the wind direction is shown in Fig. 9. This indicates that the configuration of three anemometers can produce different output patterns for each wind direction.

The experiment of the ability of mobile robot to track odor plume is accomplished in the room by spraying butane gas with a distance of 80 cm and 160 cm from the robot, as shown in Fig. 10. The results of gas localization using only stereo gas sensors in stable air and turbulent air are shown in Table 1. This shows that the success rate of mobile robot to find gas source in stable air, and turbulent air are 23%, and 13%, respectively. Meanwhile, Table 2 shows the results of gas localization testing using a stereo gas sensor accompanied by a wind direction sensor. This shows that the success rate of mobile robot to find gas source in stable air, and turbulent air are 97%, and 90%, respectively. The trajectory robot to trace odor plume can be seen in Fig. 11.

TABLE I. GAS LOCALIZATION WITHOUT WIND SENSOR

| Distance (cm) | The Success Rate at Orientation (%) | | |
|---|---|---|---|
| | 0° | 45° | +45° |
| **In Stable Air** | | | |
| 80 | 60% | 20% | 0% |
| 160 | 60% | 0% | 0% |
| Average | 60% | 10% | 0% |
| Total Average | 23.33% | | |
| **In Turbulent Air** | | | |
| 80 | 40% | 0% | 0% |
| 160 | 0% | 0% | 0% |
| Average | 40% | 0% | 0% |
| Total Average | 13.3% | | |

TABLE II. GAS LOCALIZATION WITH WIND SENSOR

| Distance (cm) | The Success Rate at Orientation (%) | | | Travel Time (seconds) |
|---|---|---|---|---|
| | *0°* | *45°* | *45°* | |
| **In Stable Air** | | | | |
| 80 | 100% | 100% | 100% | 11.9 |
| 160 | 100% | 80% | 100% | 20.8 |
| Average | 100% | 90% | 100% | |
| Total Average | 96.6% | | | |
| **In Turbulent Air** | | | | |
| 80 | 100% | 100% | 80% | 14.3 |
| 160 | 100% | 80% | 80% | 31.1 |
| Average | 100% | 90% | 80% | |
| Total Average | 90% | | | |

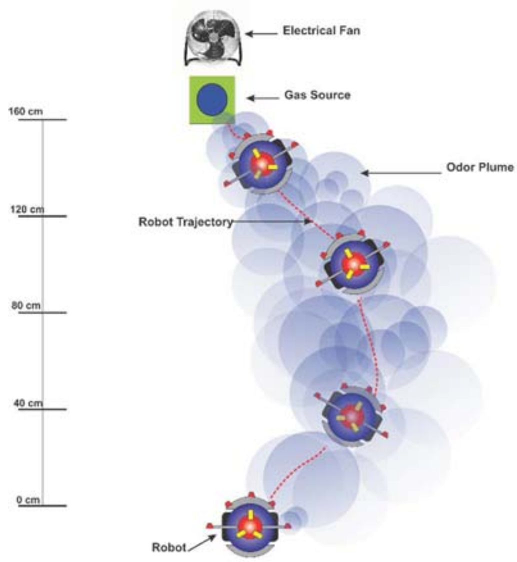



Fig. 11. The robot trajectory to odor plume.

## IV. Conclusion

This study has developed a mobile robot to search for gas source. The robot is equipped with two gas sensors to guide the robot to find the gas source and three thermal anemometers to determine the wind direction. The Intel Curie module is used as a microcontroller that handles all electronic system, both for obtaining sensor signals, and for the movement of the robot. Experimental results show that the wind has an important role in gas mass transfer. The addition of wind direction sensor can improve the robot's ability to find gas source. The robot also does not lose track of the odor plume in turbulent air. The success rate of the olfactory mobile robot to localize gas sources is 90%.

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