Implementation of Hot-Wire Anemometer on Olfactory Mobile Robot to Localize Gas Source

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***Abstract*— Wind is a major factor that can inhibit the process of tracking the source of gas leakage by the olfactory mobile robot, as it can reduce and even remove the gas concentration. This will cause the robot to take a long time to find the source of the gas leak, even fails. Therefore, this study has implemented anemometer to help the robot to determine the direction of the gas source. A hot wire anemometer is a tool used to measure wind speed by utilizing heated wire filaments. The nickel wire is wrapped to a semiconductor temperature sensor and is supplied with a constant current resulting in a temperature of 60 °C. The Neural Network algorithm is used to determine wind direction based on the pattern of temperature change values on four anemometers. The experimental results showed that this anemometer has an accuracy rate of 88%. In addition, the application of anemometer on the olfactory mobile robot can help the robot's movement towards the target so that it can improve the success rate.**

Keywords*— *Hot-wire anemometer, Neural network, Olfactory mobile robot

I. INTRODUCTION

Recently, the development of gas detection has been developed by several researchers. In general, robots use gas sensors to detect the gas leaks. This method is enough to detect the source of gas leakage, but the search for the gas location will take a long time because the surrounding wind can reduce the sensitivity of the gas sensor. The time taken by the robot to find the source of the gas leak at the distance of 9.62 meters is 232 seconds, and at the distance of 16.02 meters is 302 seconds [1]. Another study with a different system, the robot takes 143 seconds for the distance of 1.9 meters [2].

The current test scheme is still indoors. However, if testing takes place outdoors, there will be a higher disturbance due to wind movement that can reduce the concentration of the gas to be tracked. Wind movement is a very important factor to be taken into account for the mobile robot in the search for gas leak location.

One type of anemometer is Self-Heated Thermo-Resistive Element Hot-Wire Anemometer. This method can be developed with a microelectromechanical (MEMS) system consisting of a thermocouple element arranged in a bridge configuration [3]. The temperature of the hot wire anemometer is controlled by using a constant current for the heating wire [4].

Therefore, in this study has applied a hot wire anemometer on an olfactory mobile robot to determine the source of gas leakage based on the direction of the distribution of gas carried by the wind. If the gas sensor cannot detect the gas concentration properly, a hot wire anemometer will be used to determine the wind source that represents the direction of the location of the gas source. The hot wire anemometer works based on the speed of the wind that strikes the heated filament wire so that its resistance changes.

II. MATERIAL AND DESIGN

A. Design of olfactory mobile robot

This olfactory robot consists of two gas sensors to track the gas source, three ultrasonic distance sensors to detect obstacles, and four hot-wire anemometers consisting of a nickel wire heater to estimate wind direction. Hot-wire anemometers are placed on top of the robot to make it easier to determine the direction of the wind blow. The configuration of the hot-wire anemometer is shown in Figure 1. The robot was powered by wheels for tank-like movement. The design of this olfactory robot has dimensions of 25 x 23.5 x 24 cm, shown in Figure 2. This type of wheels has the advantage of better movement in areas with difficult terrain. This chain wheels move smoothly on the mound, capable of "stepping on" the obstacles and hollow paths. Figure 3 is a top view of the mobile robot equipped with the hot wire anemometers.

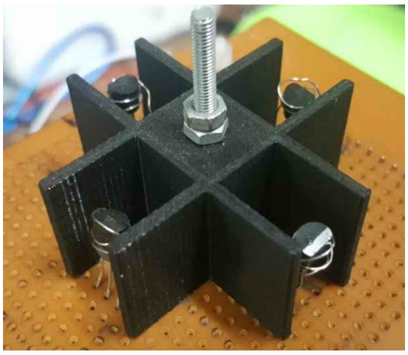

Fig. 1 The configuration of the hot-wire anemometers.

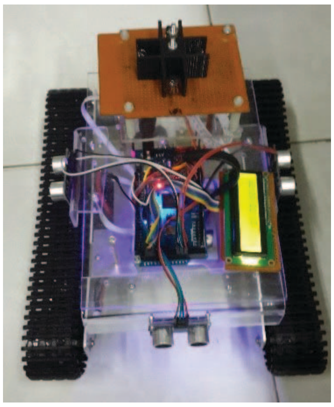

Fig. 2 The olfactory mobile robot equipped with hot-wire anemometers

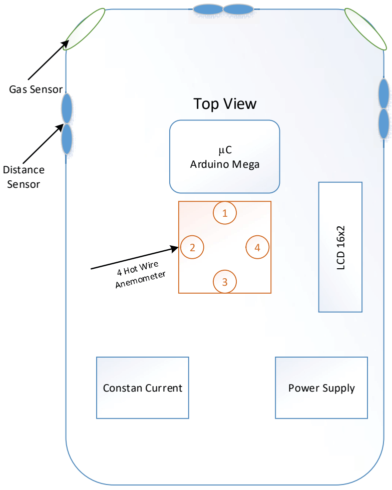

Fig. 3 The top view of the olfactory mobile robot

B. Hot-wire anemometer

The hot wire consists of a nickel material with a diameter of 0.3 mm and a resistance of 2.1Ω. This wire is wrapped around the body of a LM-35 temperature sensor. If the wire resistance is lower, the required current is higher to obtain a target temperature. In this study, the temperature of 60 °C is obtained from a constant current of 0.59 A. If there is a wind that hit the anemometer will cause changes in temperature that forms a certain pattern in accordance with the direction of the wind.

The block diagram of the hot wire system is shown in Figure 4. To determine the direction of the wind, the method of pattern recognition of artificial neural networks is used. The learning phase of artificial neural networks is accomplished on a personal computer. The weight and bias values obtained from this learning phase will be used for the testing phase of the neural network implemented in the Arduino microcontroller.

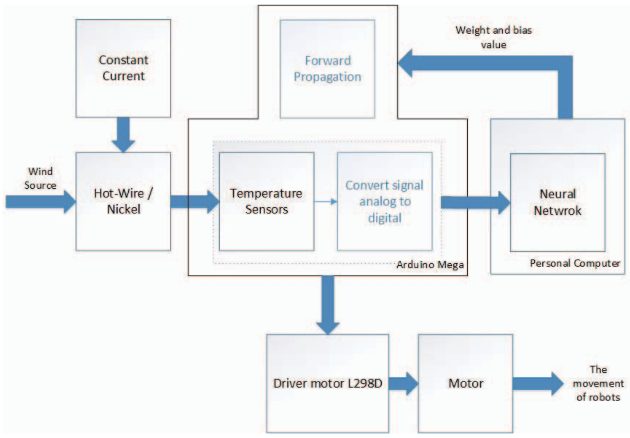

Fig. 4 The diagram of hot-wire anemometer system

Calibration is required to know the accuracy of wind direction recognition produced by this method. The wind tunnel is used in the calibration process to provide a wind source with direction changes of 30, 45, and 60 °. In this test will be applied the different wind speeds ranging from 1.7 to 6.2 mph. The wind tunnel used in the experiments is shown in Figure 5. The wind tunnel has a box shape of 105 cm in length. The wind tunnel has a 12 V fan wind source. The wind generated by the fan will be fixed in the "air rectifier" so that wind turbulence does not occur.

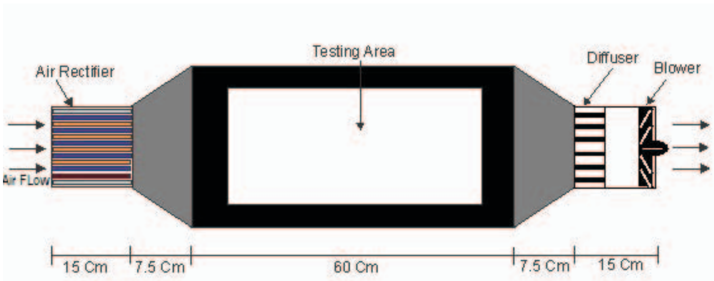

Fig. 5 The design of the wind tunnel for experiment.

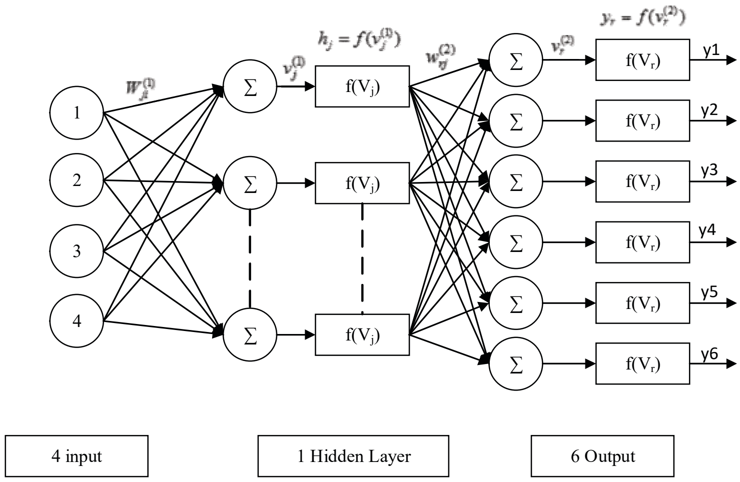

Fig. 6 The Architecture on neural network for hot-wire anemometer

C. *Neural Network*

In the study, the artificial neural network is using backpropagation method that serves to classify wind direction. The pattern produced by the four anemometers are used as the neural network inputs. The hidden layer has ten neurons and, the output layer has six neurons. The neural network architecture is shown in Figure 6. The neural network will be trained to recognize the wind direction by using a number of iterations in which the mean square error (MSE) of 0.001 is reached.

The training phase begins with the initialization of weights randomly in the hidden layer $\left(w_{ji}^{(1)}\right)$, the output layer $\left(w_{rj}^{(2)}\right)$, and the biases of the hidden layer $\left(b_j^{(1)}\right)$, the output layer $\left(b_j^{(2)}\right)$. The sum of the hidden layers in unit $-\,j$ $\left(v_j^{(1)}\right)$ is determined by Eq. (1),

$$v_j^{(1)} = b_j^{(1)} + \sum_{i=1}^{n} x_i w_{ji}^{(1)}, \quad j = 1,2,\ldots,h \tag{1}$$

The result of the feedforward process is y, which can be calculated by using Eq. (2),

$$f(v_j) = \frac{1}{1+e^{-2\alpha v_j}} \tag{2}$$

The next step is backpropagation to update the weights and biases. If the Error value is greater than Error target, the update process is applied to each layer. The updating of the weights and biases of the output layer are expressed by Eq. (3) and Eq. (4), while in the hidden layer are expressed by Eq. (5) and Eq. (6).

$$w_{rj}^{(2)}(k+1) = w_{rj}^{(2)}(k) + \mu\delta_r^{(2)} x_{xout,j}^{(1)} \tag{3}$$

$$b_r^{(2)}(k+1) = b_r^{(2)}(k) + \mu\delta_r^{(2)} \tag{4}$$

$$w_{ji}^{(1)}(k+1) = w_{ji}^{(1)}(k) + \mu\delta_j^{(1)} x_i \tag{5}$$

$$b_j^{(1)}(k+1) = w_{ji}^{(1)}(k) + \mu\delta_j^{(1)} \tag{6}$$

III. Result

There are several stages in this study, namely the measurement of the hot-wire anemometers using the wind tunnel, the testing of the neural network using the wind tunnel, the testing of the method using wind source of the fan, and the implementation of the anemometer on the olfactory mobile robot to localize the gas source.

A. *Calibration using wind tunnel*

The hot wire anemometer data is the average value of 100 temperature sensor data within 15 seconds. Measurements were made 10 times for each direction. The results of wind calibration using this wind tunnel will be used in the neural network learning phase. The normalized patterns of anemometers in the direction of 30, 45,60, and 90° are shown in Figure 7 to 10.

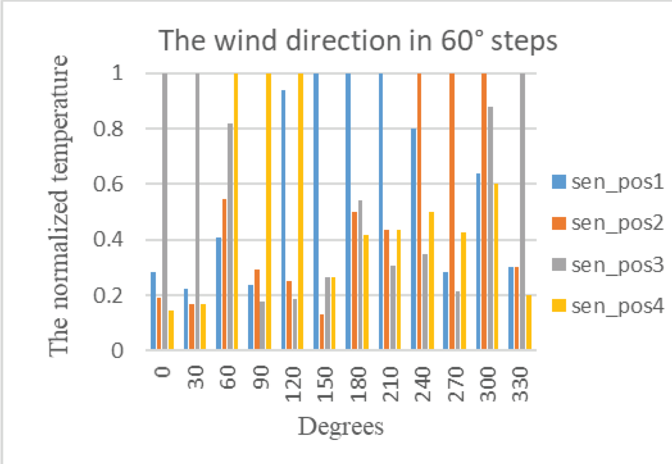

Fig. 7 The anemometer patterns of wind direction in 30° steps.

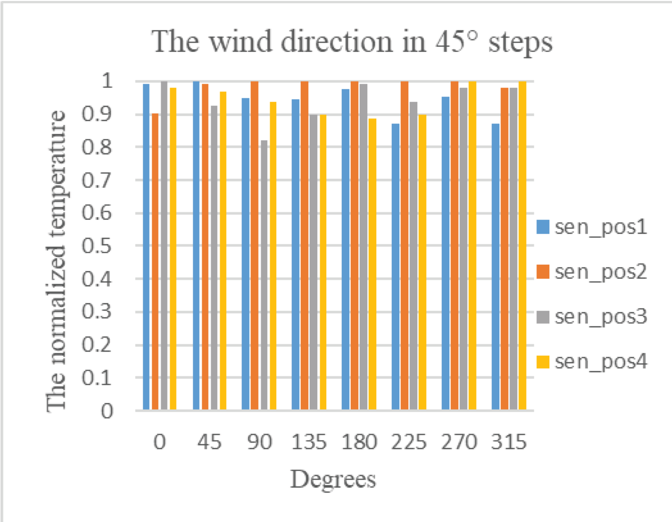

Fig. 8 The anemometer patterns of wind direction in 45° steps.

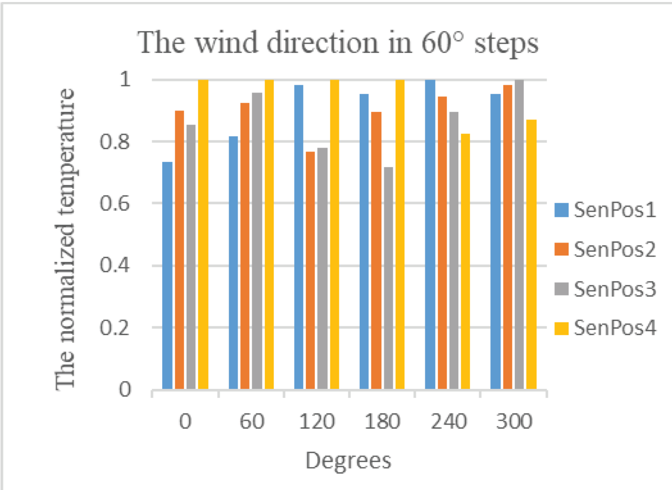

Fig. 9 The anemometer patterns of wind direction in 60° steps.

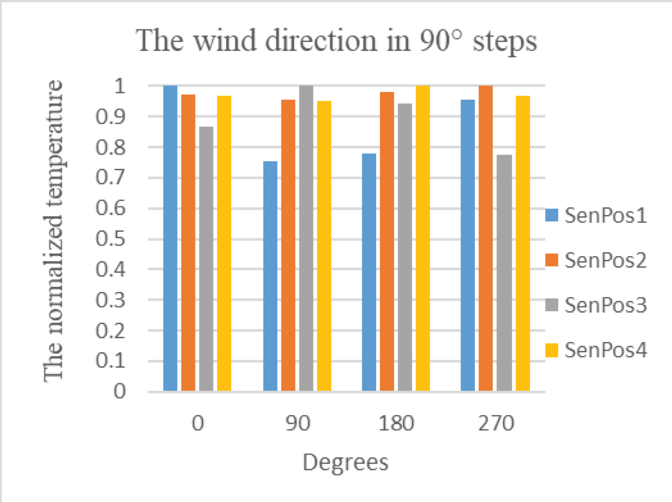

Fig. 10 The anemometer patterns of wind direction in 90° steps.

B. Prediction of wind direction in the tunnel

Neural network testing is performed to determine the level of accuracy in predicting wind direction after the learning phase. All data used for training and testing of neural networks are the result of experiments using wind tunnel. The results of the testing phase of this method for 30, and 45° steps are shown in Table 1, and 2, respectively. This shows that the accuracy level for both 30, and 45 ° steps are 50%. While the results of the testing phase of this method for 60, and 90° steps are shown in Table 3, and 4, respectively. This shows that the accuracy level for both 60, and 90° steps are 100%.

Table 1. The test results of the anemometer method in 30° steps

Angle	Hot-wire value
0°	0°
30°	0°
60°	330°
90°	120°
120°	120°
150°	210°
180°	180°
210°	180°
240°	240°
270°	300°
300°	300°
330°	0°

Table **2** The test results of the anemometer method in 45° steps

Angle	Hot-wire value
0	0°
45°	0°
90°	90°
135°	90°
180°	0°
225°	225°
270°	315°
315°	315°

Table 3 The test results of the anemometer method in 60° steps

Angle	hot-wire value
0°	0°
60°	60°
120°	120°
180°	180°
240°	240°
300	300°

Table 4 The test results of the anemometer method in 90° steps

Angle	Hot-wire value
0°	0°
90°	90°
180°	180°
270°	270°

C. Prediction of wind direction in the room

The next test is the measurement of the hot-wire anemometer response to the fan wind source in a room. This test is intended to determine the accuracy of wind direction predictions that have many disturbances such as turbulence and bouncing winds. This test is accomplished by giving several values of distance, direction and wind speeds. The results of this test are shown in Table 5.

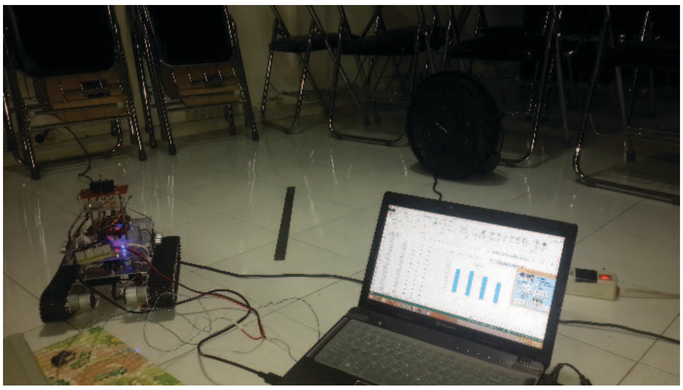

Fig. 11 The retrieval of data using wind resources 220V AC fan

Table 5 The test results of the anemometer to various parameters of wind source.

Distance (cm)	Wind Velocity (mph)	Angle	Sensor Prediction
35	4.8	0	0
		60	60
		120	120
		180	180
		240	240
		300	300
60	1.4	0	0
		60	60
		120	120
		180	180
		240	240
		300	300
60	7.4	0	60
		60	60
		120	120
		180	180
		240	240
		300	240
100	0.3	0	0
		60	120
		120	120
		180	180
		240	240
		300	300
120	6.6	0	0
		60	60
		120	120
		180	180
		240	240
		300	240
270	4.2	0	0
		60	60
		120	120
		180	180
		240	240
		300	240
340	3.4	0	60
		60	60
		120	120
		180	180
		240	240
		300	300

It can be seen that the error in predicting the wind direction only occurs in directions 0, and 300°. Therefore, this method has an accuracy rate of 88 %.

Table 6 Implementation of hot-wire anemometers on the olfactory mobile robot to localize the gas source.

Distance (m)	Time (second)
0.7	45
1	51
1.5	72
2	89

Based on the results of the previous testing, the 60 ° step angle is selected to be implemented on the olfactory mobile robot. The testing results of the olfactory mobile robot equipped with hot-wire anemometers are shown in Table 6. The fastest result to reach the target wind source takes 45 seconds at a distance of 700 cm. The farther the wind source, the longer the robot finds a target that can be affected by the surrounding air disturbance.

IV. Conclusion

In this study, hot wire anemometer has been developed to analyze wind direction. A neural network is used to predict wind direction by using the response patterns generated by hot-wire anemometers. The experimental results show that the best wind direction is obtained when using a 60° step angle with a success rate of 88%. Implementation of anemometers in the olfactory mobile robot can improve the accuracy in achieving the target.

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