Unmanned Surface Vehicle Navigation Based on Gas Sensors and Fuzzy Logic Control to Localize Gas Source

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Abstract. Oil spills can damage marine ecosystems that threaten organisms living in water. Oil spills can also evaporate which can cause air and soil pollution around it. In this study, a prototype of an Unmanned Surface Vehicle (USV) has been constructed to localize gas source. This vehicle is equipped with two gas sensors to detect the presence of gas and predict the direction of the gas source. The gas concentration received by the two gas sensors determines the speed of each propeller motor to approach the gas target. The fuzzy logic control system is applied to the USV navigation. The result shows that the USV prototype is able to approach and locate the target with the average accuracy achieved in searching of gas source location is 90.1%.

Keywords—USV Navigation, gas sensors, fuzzy logic control

1. Introduction
Spilled oil which is usually in the form of crude oil often occurs in marine waters due to leakage of tankers, as well as oil drilling. Spilled oil can also be heavy oil released by large vessels. The oil spills can damage the environment, especially the marine ecosystem. Oils can evaporate due to exposure to sunlight that can be carried by wind to land. On the land, the gas can be washed away by rain and will be absorbed into the soil. It can contaminate soil and ground water [1]. Therefore, it is important to deal with the problem by finding the location of the oil spill.

Nowadays robots can be used to help human activities, especially in hazardous environments. Mobile robot equipped with gas sensor has been developed for gas level mapping [2]. Hot-wire anemometers are applied to mobile robot to localize gas sources especially for outdoor applications [3]. A stereo electronic nose-based mobile robot for gas inspection has also been developed [4]. This robot has two sets of three metal oxide gas sensor. The use of multiple gas sensors in the robot makes it possible to find the location of the gas source accurately [5].

Unmanned Surface Vehicle (USV) is a crewless vehicle used on the surface of the water. In this study, a USV equipped with two gas sensors is used to locate a gas source. Fuzzy logic control is employed to navigate the vehicle to move towards the target. The gas concentration received by both the right and left gas sensors will affect the speed of the right and left propeller motors.
2. Method

2.1. The USV Prototype

The USV prototype has two motors as the vehicle movement drivers controlled by the fuzzy logic method. The control system is applied to the Arduino Mega 2560 module. The USV prototype is equipped with two MQ-4 metal oxide gas sensors located on the right and left sides of the vehicle, shown in figure 1. This sensor system is equipped with a suction pump to draw air containing gas to increase its sensitivity. The gas concentration represented by the voltage responses from the gas sensors will be the input for the fuzzy logic controller to determine the right and left motor speed of the propeller. The block diagram of the USV system hardware is shown in figure 2.

![Figure 1. The USV Prototype used in the experiment.](image1)

![Figure 2. The hardware schematic of the USV system.](image2)
2.2. The Design of Fuzzy Logic Control

Fuzzy logic control allows a system to process reasoning linguistically so it does not require complicated mathematical equations. Block diagram of fuzzy logic control is shown in figure 3. Fuzzy logic control has several stages which are fuzzification, inference machine, and defuzzification. The design of fuzzy logic control implemented in the USV prototype is shown in figure 4.

![Figure 3. Block diagram of the fuzzy logic control.](image)

The input data are the voltage responses of the two gas sensors, while the output are 8-bit Pulse Width Modulation (PWM) values to adjust the motor speed. Both the gas sensors have different offsets, therefore, each sensor response needs to be subtracted by initial value as a baseline. The baseline value is the sensor response to clean air. The analog voltage of the gas sensor is converted into digital value by 10-bit Analog to Digital Converter (ADC). The steps in fuzzy logic control for vehicle movements are as follows:

1) Fuzzification: This process converts crisp input into fuzzy input [6]. The crisp input are the error and delta error values. The error value is the difference between the right and left gas sensor values. While the delta error is the difference between the current and previous error values. Both have the same input membership function shown in figure 5. The input membership function consists of five variables which are Negative (N), Negative Small (NS), Almost Zero (AZ), Positive Small (PS), and Positive (P).
2) Inference machine: In this stage, the fuzzy rule is used to control system logically to correlate between input and output variables [7]. This rule is a “If – Then” logic expressed by equation 1.

\[
\text{if } X_1 \text{ is } A_1 \text{ and } \ldots \text{ and } X_n \text{ is } A_n \text{ then } Y \text{ is } B
\]

(1)

The rule base is shown in table 1. The decision making process in this study employs min mechanism to create an appropriate fuzzy output expressed by equation 2.

\[
\mu_B(y) = \min[\mu_{A_1}(\text{input}(i)), \mu_{A_2}(\text{input}(j)), \ldots]
\]

(2)

**Table 1.** The rule base of the fuzzy logic control.

| Delta Error | N  | NS | AZ | PS | P  |
|-------------|----|----|----|----|----|
| N           | Big - | Big - | Big - | Small + | Big + |
| NS          | Big - | Small - | Small - | Small + | Big + |
| AZ          | Big - | Small - | Zero | Small + | Big + |
| PS          | Big - | Small - | Small + | Small + | Big + |
| P           | Big - | Small - | Big + | Big + | Big + |

3) Defuzzification: This process converts the fuzzy output into the crisp value [8]. In this design, the output membership function is defined as singletons of ΔPWM (Pulse Width Modulation) shown in figure 6. The method used for defuzzification is a Center of Area (COA) expressed by equation 3.

\[
Z_o = \frac{\sum_{i=1}^{n} \mu(Z_i)Z_i}{\sum_{i=1}^{n} \mu(Z_i)}
\]

(3)

where \(Z_o\) is an output value of ΔPWM, \(\mu(Z)\) is the degree of membership, and \(Z\) is the crisp value of the output data.


\[ \text{PWM}_{\text{right}} = 31.37 - \Delta \text{PWM} \quad (4) \]
\[ \text{PWM}_{\text{left}} = 31.37 + \Delta \text{PWM} \quad (5) \]

Figure 6. The output membership function of the fuzzy logic control

3. Experimental Result

3.1 The USV speed

In this experiment, certain PWM values is given to the motors to determine the speed of USV. The result is shown in table 2.

| PWM (%) | Speed (ms⁻¹) |
|---------|--------------|
| 23.53   | 0.12         |
| 31.37   | 0.17         |
| 39.22   | 0.21         |
| 47.06   | 0.23         |
| 54.90   | 0.28         |
| 62.75   | 0.31         |
| 70.59   | 0.35         |
| 78.43   | 0.38         |
| 86.27   | 0.39         |
| 94.12   | 0.42         |
| 100     | 0.47         |

3.2 The Gas Sensing

In this experiment, the evaporating gasoline is used as the gas source located at certain angles with the distance of 20 cm from the USV. The direction of the USV is 90° as shown in figure 7, while the result is shown in table 3.
Table 3. The measurement of gas sensing on the USV

| Gas Location (degrees) | Output Voltage (Volts) |
|------------------------|------------------------|
|                        | Right Gas Sensor | Left Gas Sensor |
| 0                      | 0.8504            | 0.8211          |
| 45                     | 0.7820            | 0.8309          |
| 90                     | 0.7576            | 0.8602          |
| 135                    | 0.7331            | 0.9189          |
| 180                    | 0.7038            | 1.0117          |

3.3 Gas Source Localization by the USV

In this experiment, the evaporating gasoline is used as the gas source located at certain angles with the distance of 60 cm from the USV. The initial direction of the USV is 90º. The data is the difference between the angle of the gas source and the direction of the USV every 200 milliseconds shown in figure 8. The direction of the USV is given by a compass module. The results show that the angle difference will decrease until a steady state error occurs which indicates that the vehicle has found the location of the gas source. When the gas source is in the direction of 15º, 45º, 135º, and 165º, the steady state errors are 3%, 19.2%, 7.5%, and 9.9%, respectively. Many factors can influence the results of the experiments such as wind direction. In the experiments, the direction of the wind changes when the gas source at the direction of 45º. It causes a deviation of the USV movement. The average accuracy achieved in searching of gas source location is 90.1%. The USV movement in searching for the gas source is shown in figure 9 and 10.

Figure 7. The gas sensing by the USV.

Figure 8. The USV response to the direction of the gas target at (a) 15º, (b) 45º, (c) 135º, and (d) 165º.
Figure 9. The USV in searching for the gas source in the laboratory: (a) the initial position, and (b) the path of movement.

Figure 10. The USV in searching for the gas source on the lake: (a) the initial position, and (b) the path of movement.

4. Conclusion and Future Work
It has been developed the navigation of USV based on gas sensors and fuzzy logic control. The gas sensors allowed the USV to locate the gas source. Five membership functions for each input and output data to provide the navigation for the USV to move towards the gas source. The average accuracy achieved in searching of gas source location is 90.1%. For the future work, the USV navigation will be carried out on a larger scale of the experiments.
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