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Gas Source Localization using Bio-inspired Algorithm for Mini Flying Sniffer Robot: Development and Experimental Investigation

Muhamad Rausyan Fikri

Information Systems, Faculty of Engineering and Technology, Sampoerna University
**muhamad.fikri@sampoernauniversity.ac.id*

ABSTRACT

In this paper, a gas source localization (GSL) using a mini quadrotor as a mini flying sniffer robot is demonstrated. The algorithm employed is based on a bioinspired algorithm from insect behavioral searching and it is constrained to perform only in 2D dimension open space area. In this study, some information is delivered such as system development, and algorithm flowchart to highlight how this study can achieve the target goal. The performance of insect behavioral based for searching the source location shows an interesting result. Where a satisfactory result to find the source position using a bioinspired algorithm is achieved. The experimental results are provided to evaluate the performance of the searching algorithm.

Keywords: Source Localization, Flying Sniffer Robot, Bio-inspired Algorithm

1. INTRODUCTION

The bio-inspired algorithm in robotics is a technique that manipulates the robot movement follows or mimics the way of a biological being to find the objective such as searching a source location through a chemical trail. Searching for source localization in an insect is an important skill to survive. A searching ability in an insect is exhibited when they contact the opposite gender pheromone for mating, avoid the predator, and searching for food. The exhibited behavior is unique and worth to be investigated by some researchers to have a deep understanding of their behavior with a purpose of implementation such as in robotics application.

The implementation of a searching technique in robotics can benefit some aspects such as for military usage [1], and disaster mitigation in the hazardous area [2]. Then, the implementation with a similar technique has been implemented such as locating a food source [3] and locating a gas leakage source [4].

In the previous study, some methods in source localization have been proposed such as the method inspired by a lobster smells a food [5], mouse searching for food navigation [6], and “zig-zagging” of moth [8] for searching a female moth. In practical, the proposed methods show an imminent result, where all the model shows their capability to search the source location. To the best of our knowledge, most of the implementation of bio-inspired for source localization is employing an autonomous ground vehicle (AGV) robot [9].

In some cases, such as the GSL occurred in the disaster area, where the terrain is difficult to be taken by AGV. The application using an unmanned aerial vehicle (UAV) becomes one of the alternative solutions to perform GSL. Some researches such as [10][11], and [12] conducted a GSL using UAV since it provides a flexible motion.

UAV can be used in some challenging terrain such as in the disaster area where the debris reduce the inefficacy of AGV or in a narrow space where the searching is depending on the agility of the autonomous vehicle. However, the use of UAV for GSL is challenging due to its limitation in flight duration and payload capability. Considering flexibility and agility provided by a UAV and payload limitation, in this study we use UAV (quadcopter) to perform GSL. A hardware design is proposed which is compact and lightweight along with employing a bioinspired algorithm based on silkworm motion to achieve the goal of GSL. Later, the term UAV platform will be said as Mini Flying Sniffer (MFS).

Therefore, this study will focus on the development of MFS based on silkworm motion as the bioinspired algorithm. The rest of this paper will elucidate the problem statement in section II. The Material and methods in section III is presented. Continue with the result performance of the algorithm in section IV. In section V, this study ends with the conclusion.

2. PROBLEM STATEMENT

In this study, a study of GSL is conducted by using an MFS. Considering the platform is a mini flying sniffer. Some parameters should be considered to achieve the research goal such as payload and time limit to perform a GSL as well as choosing for an appropriate MFS.

In this study, the MFS provided by Parrot Inc is employed with specifications such as time of flight approximately 10 minutes without additional payload. If the payload is added the time of flight reduced to 5-8 minutes. The capability to carry the payload is up to 40 grams for the maximum weight. Thus, from the payload information the system and algorithm design for MFS should properly fit the limit such as the payload should 40 grams or less, and the duration of flight should below 10 minutes to achieve a success GSL.

3. MATERIAL AND METHODS

3.1. MINI FLYING SNIFFER HARDWARE DESIGN

In this section, the focus is on the development the MFS design and silkworm algorithm for searching method. The design for a system for MFS consists of hardware (sensors, processing unit, and battery) as well as a component such as the digital filter to be implemented. Those mentioned parameters are vital. Where the payload should not exceed from the limit. A careful and proper design should be a priority. Then, the design for the MFS is shown in Figure 1.

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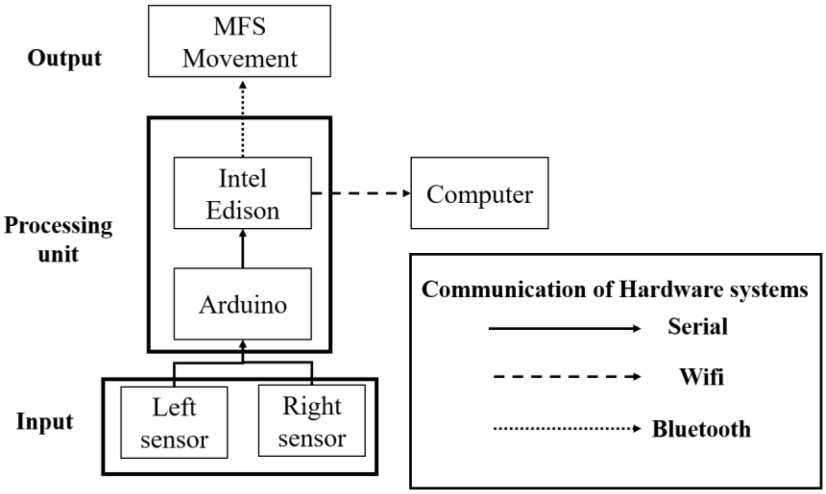

FIGURE 1. Hardware system for MFS.

An Arduino Nano is used to execute the input from the sensor and intel Edison to process initial command from the computer and process the calculation to determine the behavior. Each component's communication such as Arduino to Intel Edison, sensors to Arduino is using serial communication. The other information for the communication has been shown in Figure 1. The next is regarding the power issue. The power distribution is divided between hardware systems and MFS separately. The battery type for MFS employs Morpillot Li-Po battery with 3.7 V 600 mAh. The battery dimension is approximately 43 x 9 x 26 mm and weighs 9.07 grams. The power source for hardware systems uses Li-Po battery 3.7 V 380 mAh, with weight approximation is 10.3 grams. Two MEMs MiCS-5524 Gas Sensor Breakout (Adafruit) are employed to detect the gas such as ethanol. In this study, the gas as the source goal is using ethanol. This sensor has small dimensions of approximately 20.0 mm x 12.7 mm x 3.1mm with a weight of 0.9 grams. The weight total for the whole hardware system is approximately 38 grams. Thus, with this detail the lightweight hardware systems that is below the allowed payload limit can be achieved. The system appearance is shown in Figure 2.

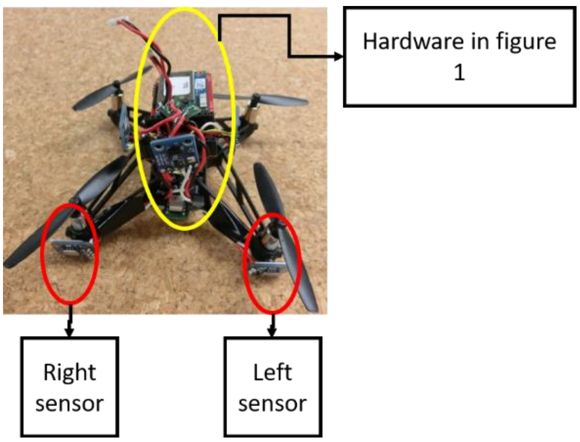

FIGURE 2. The final position condition of hardware system and MFS. The sensor left and right side are stated based on the heading direction of MFS.

3.2. BIOINSPIRED ALGORITHM

In section 3.1, after successfully achieved the target as already stated in the problem statement which is the payload weight. Now, as the payload already determined. The next is to formulate the algorithm for GSL. The algorithm design is shown in Figure 3.

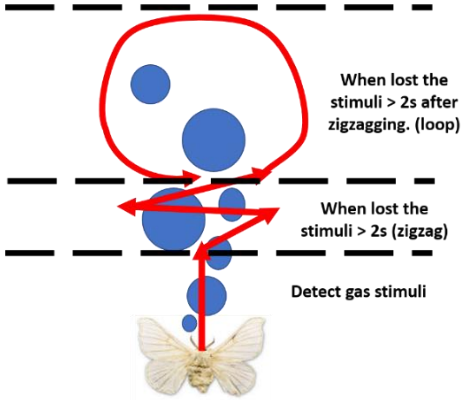

FIGURE 3. The silkworm behavior shows a detect stimuli where we call as surge, then zigzag and looping.

In this study, the duration for each step is set 0.5 seconds for a surge when detects gas from the source, 2 seconds for zigzag after the gas trails vanished. Then, after 2 seconds from zigzag, the MFS performs a loop. To perform the exact silkworm motion, the flow of data from the detection until converted to MFS motion needs a proper design. As a reference, Figure 4 shows the entire data flow before a silkworm motion is performed in MFS.

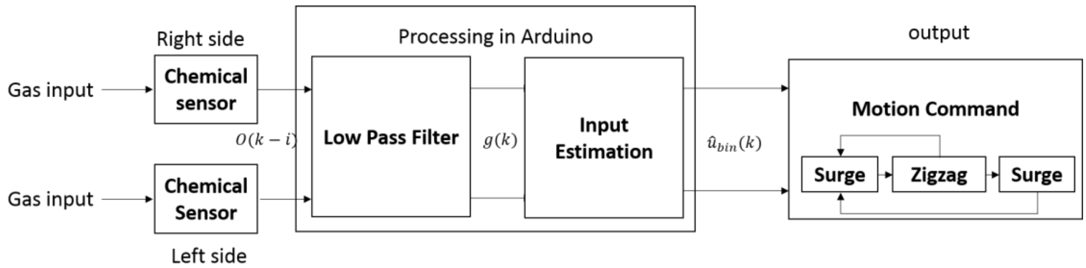

FIGURE 4. The gas information flows from chemical sensor until it transforms to output of motion command

Before the information becomes a command, the gas information is converted into must be evaluated by using a low pass filter technique (LPF). This technique enables the systems to recognize the data after reducing the noise that is detected along with gas information. In this study, a moving average LPF (MA-LPF) is performed which denotes in equation (1).

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$$\bar{s} = \frac{1}{n}\sum_{i=1}^{N} s(k-i), \tag{1}$$

where $\bar{s}$ denotes the resulting average from the input of gas information, $s(k-i)$ as the previous data of the sensor getting the gas information, and n is the desired number data. The result will give gas information data with reduced noise.

After the data obtained and the noise can be reduced into the desired value. An autoregressive exogenous model (ARX-model) is used to estimate the data is correct or not. Where, the formulation is defined in equation (2):

$$\hat{s}(k) + a_1\hat{s}(k-1) + \cdots + a_n\hat{s}(k-n) = b_0 + b_1\bar{s}(k-1) + \cdots + b_n\bar{s}(k-n) \tag{2}$$

Here $\hat{s}(k)$ denotes an estimation data of $\bar{s}(k)$, which a_1, b_0, and b_1 are determined using MATLAB System Identification Toolbox. When the data is successfully estimated, then, the correctness of the data is evaluated by using piecewise decision m, which denotes by

$$m = \begin{cases} 1, & if\ \hat{s}(k) \leq \delta \\ 0, & if\ \hat{s}(k) > \delta \end{cases} \tag{3}$$

where m denotes the decision of the MFS should perform a bioinspired searching in figure 3 or not with the case of the value from (2) is satisfy (3).

4. EXPERIMENTAL SETUP AND RESULT

Here some parameters set for the experimental design. The gas flow is continuous flow rate 1 liter per minute and wind speed 0.65 meters per second. The dimension area for the test is 2×2 meters and the MFS will conduct 10 trials to perform GSL. The gas material is used the ethanol with 99% concentration. The focus of the searching is two-dimension area where the height of MFS stationary is 1 meter. Furthermore, the success and unsuccess criteria are decided by duration of the searching. Each attempt is known as a success if the duration is < 90 seconds, and the attempt is known as unsuccess if the duration is exceeded from 90 seconds. Thus, the arrangement of environmental design for experiments can be seen in figure 5.

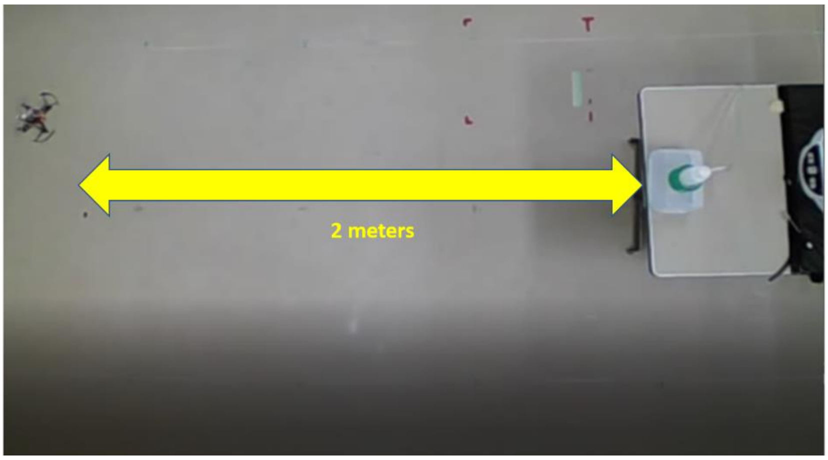

FIGURE 5. The area setting for GSL where the experimental area dimension is 2 × 2 meters.

In this study, the MFS is successfully obtained success ratio 70% to search the gas source by using the environmental design shown in Figure 5. The result is shown in figure 6, where the trajectory of the success in searching is provided.

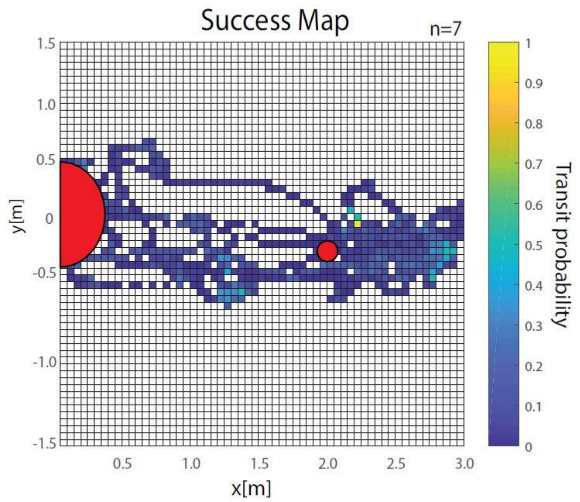

FIGURE 6. Result trajectory during GSL experiment with the number of success shown in top of figure.

It is interesting to know that the MFS performance yields a 70% success ratio, which means that the algorithm implemented into MFS has a significant effect in this trial with the given payload (see section 3, subsection 3.1). This result marks that the MFS is successfully achieving the research goal. On the other hand, the failure occurred during this research because of the MFS have done a false detection and unable to finish the searching because of running out of the battery. Yet, this result is significant to confirm that the bioinspired algorithm can be implemented in

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a flying sniffer to search the gas. The rest of the result information can be seen in Table 1.

TABLE 1.
GSL performance

	Information
Number of trials	10
Success attempt	7
Failure attempt	3
Success ratio	70%
Unsuccess attempt ratio	30%
Success flight duration	≈ 60 seconds
Unsuccess flight duration	> 90 seconds

5. CONCLUSION

In this study, the study of GSL using MFS is successfully conducted. Where other research targets are also achieved. First, the payload design satisfies the payload limitation, even further it is below the limit payload that can be carried by a mini flying sniffer. Then, the second is the effectiveness of searching using bioinspired algorithm yields a significant result where 70% of the trials can locate the source of the gas. Through the experimental validation, the study that has been conducted is believed to be satisfying by showing 70% success in searching as well as achieved a design that is compact and lightweight with the constraint explained in section 2.

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