Odor Localization using Gas Sensor for Mobile Robot

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***Abstract*—This paper discusses the odor localization using Fuzzy logic algorithm. The concentrations of the source that is sensed by the gas sensors are used as the inputs of the fuzzy. The output of the Fuzzy logic is used to determine the PWM (Pulse Width Modulation) of driver motors of the robot. The path that the robot should track depends on the PWM of the right and left motors of the robot. When the concentration in the right side of the robot is higher than the middle and the left side, the fuzzy logic will give decision to the robot to move to the right. In that condition, the left motor is in the high speed condition and the right motor is in slow speed condition. Therefore, the robot will move to the right. The experiment was done in a conditioned room using a robot that is equipped with 3 gas sensors. Although the robot is still needed some improvements in accomplishing its task, the result shows that fuzzy algorithms are effective enough in performing odor localization task in mobile robot.**

Keywords— odor localization; fuzzy logic; TGS.

I. INTRODUCTION

The development of odor localization research has grown widely and rapidly. Most of the researches used static [1] and dynamic instruments [2], [3], [4]. In static system, the gas sensors were placed in determined spots. Some drawbacks of them occurred, such as ineffectiveness of the sensors due to the working areas of sensors that were limited by the static range between the sensors and the sources. It is contradictive with the dynamic system, i.e. the use of mobile instruments where the gas sensors are integrated to mobile robots or mobile devices. Being integrated to the mobile robots makes the gas sensors be able to reach wider areas. Although the range between the gas sensors and the sources still influence the working areas of mobile sensors, the wide areas can be achieved by mobile characteristics of the robots where gas sensors placed.

The localization of odor sources were widely investigated by researchers using simulation [5], [6], [7] or real experiments [8], [9], [10]. The effectiveness of the robots in localizing the sources depends on the methods used. Some of the previous researchers used the algorithms as follows: 1. imitated the behavior of the animals (chemotaxis and anemotaxis) [11], [12], [13]; 2. based on the flow of the fluid (fluxotaxis) [14], [15], [16]; 3. used entropy of the posterior probability field (infotaxis) [17], etc. However, most of the algorithms has drawbacks, such as low search accuracy and efficiency due to their dependence on the wind direction [18]. Jiandong [18] tried to find another way using fuzzy logic to localize the odor. The path where the robot should go was determined by the rate change of the plume sensed by the 3 sensors mounted on it. Fuzzy logic was successful in controlling the trajectory of the robot. Even though, the validation of the fuzzy logic was done only in simulation. It was far from the real one. In this research, a real robot was developed and implemented in a real experiment. The robots were equipped with some gas sensors that have a task to supply the inputs data to the fuzzy logic algorithm.

Some other researchers also used fuzzy logic in their experiments of odor localization [19], [20], [21], [22]. Most of them used fuzzy to control the communication network. X. Cui [19] implemented fuzzy logic in swarm robots of mobile sensor networks. It is used to control nodes of the sensor network in determining the next optimal node deployment location. Siti Nurmaini in [20] proposed Fuzzy-Kohonen Networks and Particle Swarm Optimization (FKN-PSO) to localize the odor source. The result was then compared to the Fuzzy-PSO. It showed that FKN-PSO was more efficient than Fuzzy-PSO.

Other researches, such as in [21] and [22], show that the fuzzy logic were used as sensor's information processor. P. Jiang [21] used fuzzy logic to process multi inputs of the sensors (olfaction, vision, wind speed/direction, distance and position of robot). More detailed and accurate decisions of these inputs were got easily using Fuzzy logic. The outputs of the fuzzy were set up into six behaviors, including obstacles avoidance, odor source declaration, nearest distance-based visual searching, up-wind searching, path planning, chemotaxis searching, and random searching. The proposed algorithm was successful in increasing the ability of the robots in finding the plume. Siti Nurmaini in [22] was successful using fuzzy logic in finding the best target position of each swarm robots. The fuzzy logic was only activated when the gas sensors were inactive and robots moved in unknown areas. When gas sensors were active, the Fuzzy-PSO was used. Fuzzy-PSO was successful to control the trajectory and movement of the robots.

In this research, the information of odor concentration from gas sensors was used to determine the track of the robots. The high concentration indicated that it was the way of the source came from. Therefore, the fuzzy output will be

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set as the position of the right and left motors of the wheels in order to determine which way the robot should take.

II. ODOR LOCALIZATION

As mentioned in part I, odor localization has impressed many researchers nowadays [5]–[10]. Recently, a number of approaches for odor localization have been presented. Kowadlo and Russel [23], Ishida [24] and Thomas Lochmatter in his Ph.D. thesis [25] described the detail work in this research. G. Kowadlo and R.A. Russell provided the odor localization approaches in a Venn diagram [23]. They divided the odor localization approaches in 3 categories: 1. Early work, 2. Reactive Gradient Climbing, and 3. Turbulence Dominated Fluid Flow. According to G. Kowadlo and R.A. Russel, the pioneers of the first category were Larcombe and Hassal.

The idea on the sensitive robot that was developed by Larcombe and Hassal was then improved by Rozas et al (1991), Buscemi et al (1994) and Genovese et al (1992) [23]. In that research, they did not consider the real characteristics of odor dispersal but they utilized chemical gradient that was operated to move to the odor source. The diffusion was assumed as the dominant-term of odor dispersal. There were a lot of researchers discussed the localization approaches using various type of robots. Ishida in [24] stated that flying and swimming robots were also interested to analyze. For the underwater robots, there were RoboLobster that was developed by Consi et al [27], Albacore REMUS autonomous underwater vehicle (AUV) that was tested by Farrel [28] and REMUS AUV was used by Wei Li [29]. For the flying robots, there were Patrick P. Neumann [30] and G. Montes [31].

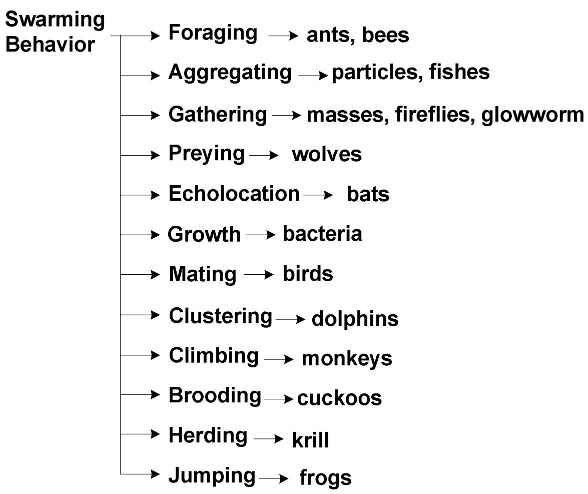

Fig. 1. Odor Localization Approaches [25], [26].

Working with odor has so many problems to consider, such as the odor characteristic, the gas sensor performance, and the experimental environment. Villarreal in [32] stated that some limitations of previous algorithms were related to the sensors processing time.

TABLE I. RECENT ODOR LOCALIZATION RESEARCH USING FUZZY

Year	Methods/Algorithm	References
2014	Fuzzy	[33]
2015	Fuzzy Fuzzy control based	[18] [21][22]
2016	Fuzzy-PSO	[34]
2017	Fuzzy-Kohonen	[20]

Sometimes, they need a long time to be ready for a second measurement (1 minute). Some strategies even required more time since they need to cover the whole area several times (more than 20 minutes) [32]. Also, the odor source was not always reached due to multiple local maxima placed near the odor source. This happens because vapors of odor source are volatile and tend to homogenize the whole area, but in the case of constant gas leaks, maximum concentration is always at the exit of the odor source [32].

This research only focused on fuzzy algorithm. Fuzzy logic is very useful in many areas of odor localization application. As mentioned in Sub chapter I, it can be used as the network controller and input sensors information processor. In this research, the information from the TGS sensors was collected and processed using fuzzy algorithm. After fuzzification, fuzzy inferencing, and defuzzification process, the PWM of the robots can be controlled in such a way so that it can reach the odor source as the final target of the robot. Some Fuzzy and their combination methods/algorithms used by the researchers of localization using fuzzy algorithm in recent years can be seen in Table I.

III. EXPERIMENTAL SETUP

A. Robot Design

The robot in this research equipped with 5 distance sensors, 3 gas sensors (TGS 2600), and 4 Omni wheels. In order to collect the experimental data, communication between robot and computer was established using X-bee. For controlling all of the components in the robot platforms, Arduino Mega was used as the embedded controller. Fuzzy controller was designed using C/C++ language.

The robot consisted of 3 layers with diameter 15 cm. Three TGS 2600 gas sensors that were used in research were placed in position -90^o, 0^o, and 90^o of the front side of the robot. The value of 0^o indicated gas sensor that was placed in the middle front of the robot, while 90^o and -90^o showed the position of the gas sensor in the right and left position with each angle 90^o from the middle front sensor. The robot also consisted some other components, such as DC DC converter, motors, LCD, battery, etc. The detailed arrangements of the robot are as follows: 1. The top layer of the robots was placed TGS Sensors, LCD and Xbee communication module, 2. In the middle layer, 5 distance sensors and Arduino Mega were mounted, 3. At last, in the bottom of the layer, 4 DC motors, 2 drivers, 1 DC-DC converter, and 1 battery 12 volt were placed. The physical form of robot can be seen in Fig. 2. The block diagram of the robot is represented in Fig. 3. The communication between the robot and the computer was established using X-bee modules.

The experiment was conducted in indoor environment of a corridor 90 cm x 500 cm room. To get an accurate data, the room was conditioned so that there was only little disturbance of wind (airflow of the wind was kept as little as possible). The room was maintained in closed conditioned. The temperature was kept between 27^0C - 30^0C and the humidity was in the range of 65% - 75%.

B. Fuzzy Logic Algorithm as Controller

The fuzzy logic was first introduced by Zadeh [35]. It is logical system that is intended to be a logic for approximate reasoning [35]. It is famous with its linguistic rules based knowledge. The rules consist of the inputs and the outputs condition. Using these rules, the robot will have an ability to decide what actions that it should take. The rules are established based on the expert knowledge, an observation of the human operators, and trough the experimental analysis, especially for the range of its membership functions.

In this research, each of gas sensors provides the inputs of the fuzzy logic. They were related to the concentration of the source around the robot that they detected. The amount of the concentration detected was the input parameters. They were then arranged into an input membership functions (MFs). From these input MFs, some rules related to the outputs action or decision taken, as the response to the inputs, were generated. These rules allowed the robot to interact with its surroundings, in this case to find a correct way to the source. By having fuzzy logic as the robot's decision maker, the robot would run to the right track in order to get closer to the source and at the end find where the source was. The fuzzy logic helped the robot to find a correct movement to the right, the left, or forward by deciding an output based on the rules generated before. The output of the fuzzy logic was related to the PWMs of the right and the left motors of the robots.

Fig. 2. Odor Localization Robot

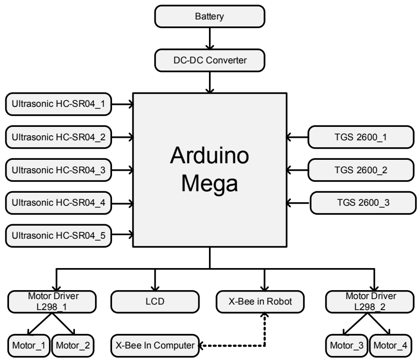

Fig. 3. Block Diagram of Odor Localization Robot

When the concentration in the right side of the robot was higher than the middle and the left side, the fuzzy logic will give decision to the robot to move to the right. In that condition, the left motor was in the high speed condition and the right motor was in slow speed condition. Therefore, the robot will move to the right.

The fuzzy logic controller system in this research was set up using some steps, i.e. Fuzzification, rule base and inference, and the defuzzification (see the flowchart Fig. 4).

Step 1. Fuzzification

In this step, the member of the fuzzy logic was determined (See Table II). Based on the linguistic variable shown in Table II, the fuzzy set was then set up using the membership variables, i.e. Low, Medium, and High. The membership function equation can be seen in equation (1) - (3), while the input membership function graph can be seen in Fig 5. The fuzzification process was set using the crisp inputs based on the equation (1) - (3).

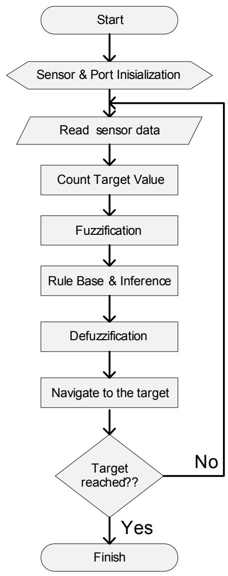

Fig. 4. Flowchart of Fuzzy algorithm

TABLE II. GAS SENSOR INPUT

Gas Concentration (ADC)	Linguistic Variable	Symbol
0-449	Low	L
50-849	Medium	M
450-900	High	H

$$\mu_{low}(x_i) = \begin{cases} 1 \; for \; a \le x < b \\ \frac{c-x}{c-b} for \; b \le x < c \\ 0 \; for \; x \ge c \end{cases} \quad (1)$$

$$\mu_{medium}(x_i) = \begin{cases} 0 \; for \; x < b \; and \; x > d \\ \frac{x-b}{c-b} for \; b \le x < c \\ \frac{d-x}{d-c} for \; c \le x \le d \end{cases} \quad (2)$$

$$\mu_{high}(x_i) = \begin{cases} 1 \; for \; d < x \le e \\ \frac{x-c}{d-c} for \; c \le x < d \\ 0 \; for \; x < c \end{cases} \quad (3)$$

Step 2. Rule Based and Inference

In this step, some rules that related to the robot intelligence were generated. These rules will determine the basic rules value in controlling robot motion. 27 rules of the fuzzy logic algorithm are presented in Table III.

Step 3. Defuzzification

Defuzification in this research used Sugeno method. This method is simple and suitable for this research. The implication function that was used in this research was Max-Min operation to certain membership function.

TABLE III. GAS SENSOR INPUT

S1	S2	S3	M1	M2	Condition
L	L	L	S	S	Go forward slowly
		M	M	S	Turn right slowly
		H	F	S	Turn right fast
	M	L	M	M	Go forward moderately
		M	M	S	Turn right slowly
		H	F	S	Turn right fast
	H	L	F	F	Go forward fast
		M	F	F	Go forward fast
		H	F	S	Turn right fast
M	L	L	S	M	Turn left slowly
		M	S	M	Turn left slowly
		H	S	F	Turn left fast
	M	L	S	M	Turn left slowly
		M	M	M	Go forward moderately
		H	F	M	Turn right moderately
	H	L	M	M	Go forward moderately
		M	M	M	Go forward moderately
		H	F	M	Turn right moderately
H	L	L	S	F	Turn left fast
		M	S	F	Turn left fast
		H	S	F	Turn left fast
	M	L	S	F	Turn left fast
		M	M	F	Turn left moderately
		H	M	F	Turn left fast
	H	L	S	F	Turn left fast
		M	M	F	Turn left fast
		H	F	F	Go forward fast

Explanation of Table III:

Inputs: (S1-S3: Gas sensors)	**Outputs: (M1-M2: Motors)**
S1: Left S2: Middle; S3: Right	M1: Left; M2: Right
L : Low; M : Medium; H : High	S : Slow; M : Medium; F : Fast

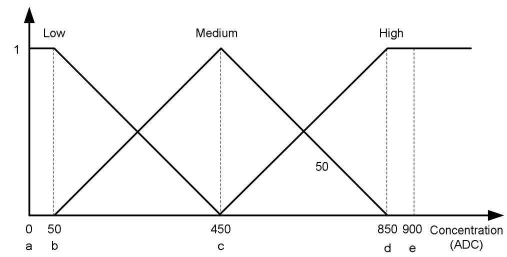

Fig. 5. Input membership function

TABLE IV. GAS SENSOR OUTPUT

PWM Motor	Linguistic Variable	Symbol
50	Slow	S
150	Medium	M
250	High	F

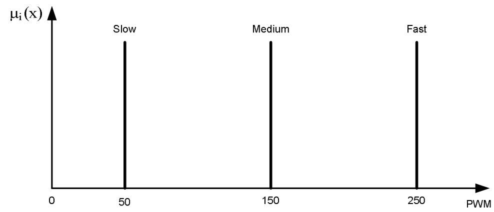

Fig. 6. Output membership function

This step produced fuzzy output value that was suitable to certain rules. The output membership function can be seen in Table IV. The Fuzzy output in this step is in a singleton form with the range 0 until 250 that was mapped into 3 linguistic variables: Slow, Medium, and Fast. The outputs related to the PWM of each of motors where the PWM value 50 indicated slow motion, 150 presented medium, and 250 showed fast one.

IV. RESULT AND DISCUSSION

A. Simulation

At first, the implementation of fuzzy in the system was simulated using Matlab. There were 3 inputs in fuzzy, namely: S1, S2, and S3 (gas sensors), while the outputs of the fuzzy in simulation were M1 and M2 that represented left and right motor. The inputs and outputs of fuzzy logic were determined in the Sugeno fuzzy logic. The range of each inputs and output membership function was referred to Fig. 5 and Fig. 6 while the fuzzy rules that manage the inputs and output of the fuzzy were set up as shown in Table III above. The defuzification process follows the Sugeno method. One of the simulation results can be seen in Fig. 7. In this example, all the inputs were set into High condition,

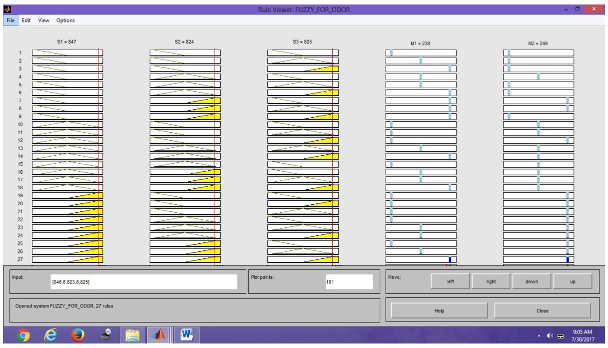

Fig. 7. Simulation using Matlab.

with the concentration value 847, 824, and 825 for S1, S2, and S3. The output value of left and right motors was in the high speed condition with PWM 238 and 249. This example is the implementation of the rule number 27 where the robot will go forward fast based on this rule.

B. Real Experiment

The experiment that was conducted in corridor of 90 cm x 500 cm was done in various starting positions. The range of the robots to the source was varied in order to analyze the effectiveness of the constructed fuzzy algorithms. Fig. 8 shows the experimental path of the robot in finding the gas source with starting point A, B, and C. The position A, B, and C were represented by Yellow, Red, and Green on the picture in Fig. 8. The position B is the position that is parallel to the source, while A and C represented the left and right position of the robot to the source. The real experimental condition is shown in Fig. 9.

In the research as shown in Fig. 9, the robot starts its searching in various distances not only at 200 cm, but also 300 cm, 400 cm, and 500 cm. At first, the robot just went to straight forward, some times, it changed its wheel position due to the input from the sensor reading. From the data shown in Fig. 10, it is known that it needed at least 38 second to reach the odor source in 200 cm distance away.

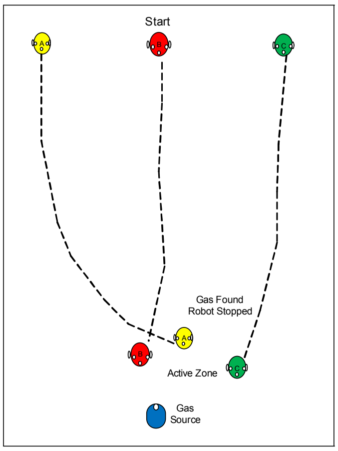

Fig. 8. The robot path in tracking the odor source.

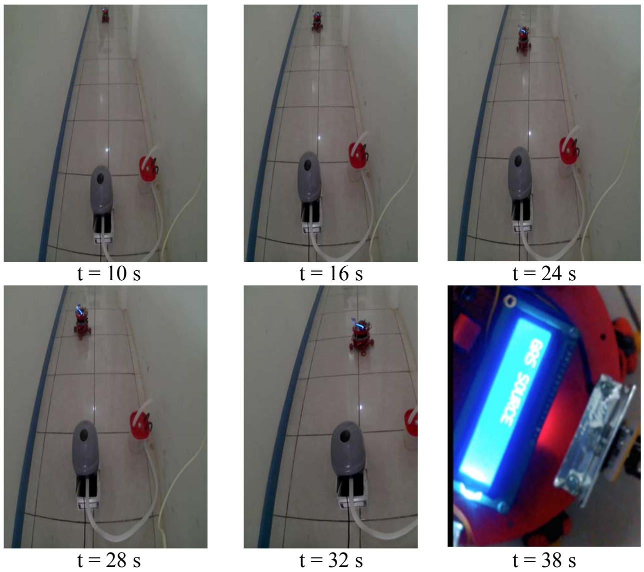

Fig. 9. Real experimental condition using B position as starting point with distance 200 m.

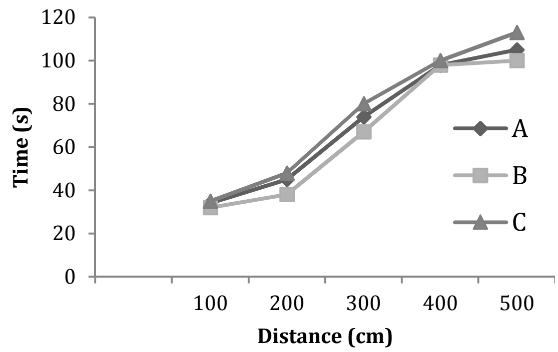

Fig. 10. Duration time needed by the robot in localizing the source

When the odor has found, the robot will stop and send the information "gas source" indication and the position to the receiver.

At the first time of its track, the robot only went forward. It is in accordance with the rules that have been set up before. For a distance of a robot that was far from the source, it usually smells a low concentration of the source. When S1, S2, and S3, were in the same condition, Low, Low, and Low, the robots will moved forward slowly. Each of the rules would be fired interchangeably based on the inputs that the robots sensed.

V. CONCLUSION

The experimental results show that the proposed fuzzy algorithm was able to be applied in real situation. It has capability to localize the odor using simple algorithm. However, it can only be applied in scalable and conditioned room. The longest experimental distance between robot and source is only 500 cm. It is far from the real world condition. It needs more experiments and researches. In doing the odor source localization, there are a lot of parameters that should be considered. The disturbances of the odor such as wind flow, temperature, and humidity affect the sensors reading. In addition, the range of the Fuzzy Membership functions should also be taken into accounts. Some analyses and observation to experimental fuzzy membership functions should be done in order to get best tuning. In this experiments, there are still some drawbacks. The robot sometimes stops in the position that is not so closed to the source. It is due to the robot is lacking the steering angle that has not been covered by the fuzzy in this experiment yet. In our future work, to enhance the performance of the robots, it is needed to add some gas sensors to get more precise input data, take into account the steering angle to the output of the fuzzy and set up a collaboration between fuzzy and other algorithms to accomplish the odor localization task.

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