Enhancement of Navigation Systems of Mobile Robots in Gas Leakage Searching

By 19_NLH

PAPER • OPEN ACCESS

Enhancement of Navigation Systems of Mobile Robots in Gas Leakage Searching

To cite this article: Nyayu Latifah Husni *et al* 2019 *J. Phys.: Conf. Ser.* **1167** 012005

Enhancement of Navigation Systems of Mobile Robots in Gas Leakage Searching

Nyayu Latifah Husni[1], Nadya Lukita[2], Masayu Anisah[3], Ade Silvia Handayani[4], Siti Nurmaini[5], Irsyadi Yani[6].

[1-4, 7] Electrical Department, Politeknik Negeri Sriwijaya
[5] Intelligent System Research Group, Faculty of Computer Science, Universitas Sriwijaya
[6] Mechanical Engineering Department, Faculty of Engineering, Universitas Sriwijaya
Corresponding author's e-mail address: siti_nurmaini@unsri.ac.id

Abstract. Gas leakage commonly happens in daily life. The leakage can cause many losses and even cause the death. Implementing human and animals in monitoring, checking, and finding the source of leakage can harm their life. The usage of the robot can give many advantages, i.e., it can be programmed easily, it does not feel tired, it does not need much time to be trained, etc. However, to control the robot in navigating to the leakage source is not so Haeasy. In this research, an enhancement of navigation system using two parameters inputs, i.e., distance and concentration of the gas is proposed. A distance fuzzy algorithm and gas fuzzy algorithm is implemented to the robot. The robot can use each parameter depends on the environment and situation that it meets. Both of the algorithms were successful in guiding the robot to move in the correct path. The robot could avoid the obstacles and find the location of the gas leakage.

Keyword: Mobile Robot, Navigation, Fuzzy Logic.

1. Introduction

One of the most important processes in industry is a transport system that functions to transmit oil or gases. Even though the transport system has been designed as good as possible, however, the failure risk is always possible to occur. If gas leakage happens, the distribution process will be hampered. To reduce the risks of leakage, periodic manual inspection is needed. However, it is not so easy, since the gas sometimes cannot be detected by human sense. The gas, such as CO is called as silent killer due to it has no color, no smell and no taste [1]. Therefore, a gas source detector for searching the leakage is really needed.

A gas detector in the form of mobile robot, that can move automatically or manually, has become an essential part in the industrial process [2]. The main advantage of robot application is to reduce the risks of an accident that occurred while checking the leakage. A gas detector that is brought by the operator to check the leakage around the industrial place can harm his life [3]. It is contradictive with the mobile robot that is safe to be implemented in a dangerous area. It is able to reach an area that cannot be reached by human [4].

In conducting its task, the robot navigation becomes a crucial part to be investigated. Sometimes. The robot cannot navigate well to the gas source leakage. It travels to the wrong direction. Therefore, a careful design should be built. A conventional system commonly utilizes a complex mathematical equation. It is usually difficult to be implemented in an unknown and unpredictable situation.

Therefore, the use of Artificial Intelligence (AI) will give more benefit than the conventional one. AI based on the knowledge, or usually called as knowledge base system. It works based on the knowledge that it has. It does not use a mathematical model of the system. Therefore, this system normally is easy to be designed [5].

In our previous research [6], a distance fuzzy logic was utilized. However, the robot could only be tested in the scalable arena. In this research, an AI, i.e., distance fuzzy logic was also integrated into the robot. To enhance the mobile robot ability in navigating to the real source leakage, the distance and concentration were combined and utilized as the inputs of the fuzzy logic. These inputs will be useful for the mobile robots to avoid the obstacles around it, while the concentration fuzzy logic will guide it to the correct direction. These two inputs will help the robot to decide which direction that it should take.

2. Navigation System Technology

A mobile robot must be able to navigate in the correct track in order to complete its task. It should be equipped with a good navigation system, so that, it can move well and decide where it should move in order to reach the target. The information for the navigation system is usually obtained from the environmental conditions. Various methods and techniques were implemented to navigation systems. According to Anish [7], there were two classes of navigation, namely: global and local navigation. Global related to the availability of the prior knowledge of the environment, while global related to the capability of the robot to decide what it should do based on the data of the input sensors. It could accomplish the task autonomously. Artificial Potential Field [8], [9], Modified spline-based navigation [10] are some of the examples of global navigation. For local navigation, researchers commonly used ANFIS [11], Fuzzy Logic [12], Genetic Algorithm [13], [14], Neural Network [15][10], Particle Swarm Optimization [16], Ant Colony Optimization [17], Neuro fuzzy [18], [19] .

There were a lot of researches using fuzzy logic algorithms as the robot navigation system in searching the gas source [5], [14], [20]. Rivai et al in [5] used the fuzzy logic for searching the location of the gas leak. A robot arm was utilized in this research. A metal Oxide sensor was integrated into the robot. The robot has been successful in locating the gas source. However, this research only focused on the navigating of the arm of the robot, not the way of the robot moved to the gas. Kandar et al in [14] used a hybrid of fuzzy logic and PSO. The result showed that using PSO as the combination of fuzzy in searching the gas source was better than single fuzzy. However, this algorithm was implemented for more than one robot, i.e., a swarm robot that made the system became more complicated. It needed extra effort to control the robots. Ping Jiang et al in [20] used multivariable fuzzy control to manage multi inputs came from various sensor. A mathematical solution was derived to simplify the fuzzy logic rules and fuzzy inference. However, the robot was equipped with a lot of sensors that made the robot needed more cost.

3. Experimental Setup

3.1. Robot Design

In this research, 5 HC-SR04 ultrasonic sensors, 5 TGS 2600 gas sensors, and 2 L298N motor drivers were integrated into the robot. The robot movement was controlled using the fuzzy logic algorithm. The inputs of the fuzzy logic came from HC-SR04 ultrasonic sensors and TGS 2600 gas sensors, while the output was used to control the PWM of the left and the right motors. Besides ultrasonic sensors, gas sensors, and also motor drivers, the mobile robot was also equipped with Arduino Mega 2560 microcontroller that acted as the controller, Xbee pro that had functioned as wireless serial data communication, and LCD that was useful as the display monitor.

The mobile robot was designed with a diameter of 14.5 cm, as shown in Figure 1. The robot consisted of 4 levels, i.e., 1) at the first level, there were 2 motor drivers, 4 DC motors, ubec, and battery; 2) at the second level, there were Arduino Mega and 5 HC-SR04 ultrasonic sensors; 3) at the third level, there were 5 TGS 2600 sensors, Xbee, HMC5883L compass; and 4) at the top level, there were LCD and switch button. The positions of the distance and the gas sensors, the diagram block, and the physical form are shown in Figure 1 and Figure 2.

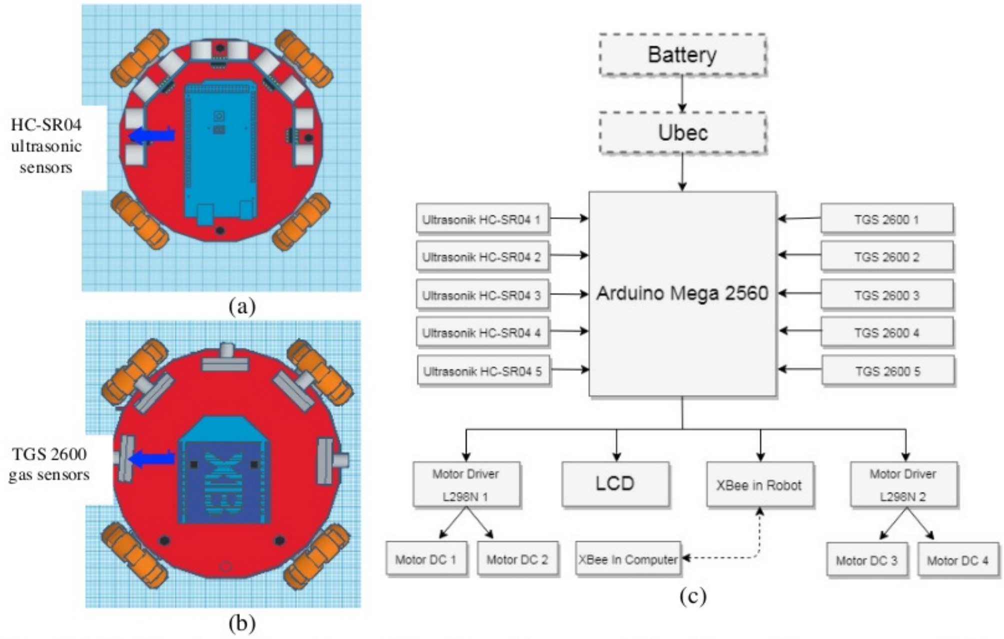


Figure 1. Mobile robots (a) positions of the ultrasonic sensors, (b) positions of the gas sensors, (c) the diagram block

(a) (b) (c) (d)

Figure 2. Physical Form of Mobile Robot from a different view: (a) top, (b) front, (c) left, (d) right.

3.2. Fuzzy Logic Algorithm as Controller

In this research, linguistic variables, namely, i) **Near, Medium, and Far** were used to indicate the distance of the robot to the experimental environment; ii**) Low, Medium, and High** were used to indicate the concentration of the gas; and ii) **Very Slow, Slow, Medium, Fast, and Very Fast** were used to indicate the duty cycles of the motors. A fuzzy rule was then designed using these linguistic variables. The basic rules were useful for the robots in deciding what it should do. The flowchart of the overall fuzzy processes was shown in Figure 3. The processes of fuzzification, fuzzy rules, and defuzzification were explained in the following section.

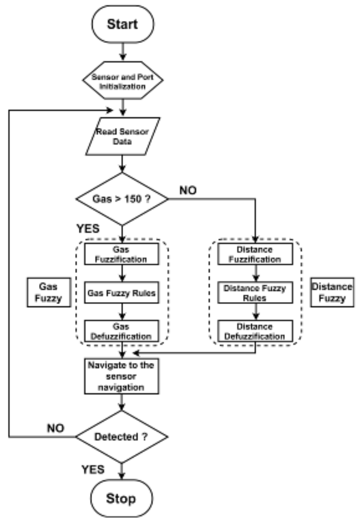


Figure 3. Flow chart of the fuzzy logic

Table 1. Input Sensor Ultrasonik HC-SR04 dan Sensor TGS 2600 Linguistic Variables

Distance Sensors			Gas Sensor		
Distance (cm)	Linguistic Variable	Symbol	Concentration (ppm)	Linguistic Variable	Symbol
10-40	Near	N	60-140	Low	L
10-70	Medium	M	60-220	Medium	M
40-70	Far	F	140-220	High	H

$$\mu_{Near}(Xi) = \begin{cases} 1 \text{ for } x < 10 \\ \frac{x-40}{10-40} \text{ for } 10 < x \leq 40 \\ 0 \text{ for } x > 40 \end{cases} \quad (1)$$

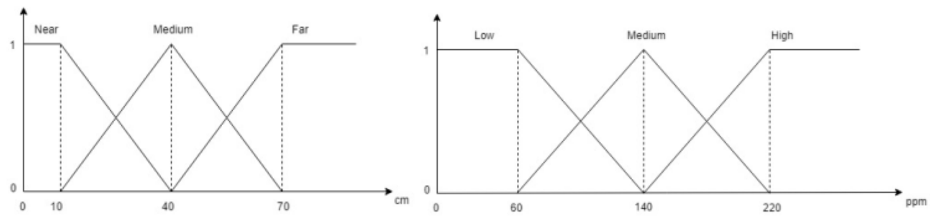
$$\mu_{Medium}(Xi) = \begin{cases} 0 \text{ for } x < 10 \text{ and } x > 70 \\ \frac{x-10}{40-10} \text{ for } 10 < x \leq 40 \\ \frac{x-70}{40-70} \text{ for } 40 < x \leq 70 \end{cases} \quad (2)$$

$$\mu_{Far}(Xi) = \begin{cases} 1 \text{ for } x > 70 \\ \frac{x-40}{70-40} \text{ for } 40 < x \leq 70 \\ 0 \text{ for } x < 40 \end{cases} \quad (3)$$

$$\mu_{Low}(Xi) = \begin{cases} 1 \text{ for } x < 60 \\ \frac{x-140}{60-140} \text{ for } 60 < x \leq 140 \\ 0 \text{ for } x > 140 \end{cases} \quad (4)$$

$$\mu_{Medium}(Xi) = \begin{cases} 0 \text{ for } x < 60 \text{ and } x > 220 \\ \frac{x-60}{140-60} \text{ for } 60 < x \leq 140 \\ \frac{x-220}{140-220} \text{ for } 140 < x \leq 220 \end{cases} \quad (5)$$

$$\mu_{High}(Xi) = \begin{cases} 1 \text{ for } x > 220 \\ \frac{x-140}{220-140} \text{ for } 140 < x \leq 220 \\ 0 \text{ for } x < 140 \end{cases} \quad (6)$$



(a) (b)

Figure 4. (a) Fuzzification of HC-SR04 Ultrasonic sensor; (b) Fuzzification of TGS 2600 gas sensor

Table 2. Output Sensor Linguistic Variable

PWM	Linguistic Variable	Symbol	note
50	**Very Slow**	VS	0
100	**Slow**	S	1
150	**Medium**	M	2
200	**Fast**	Fa	3
250	**Very Fast**	VFa	4

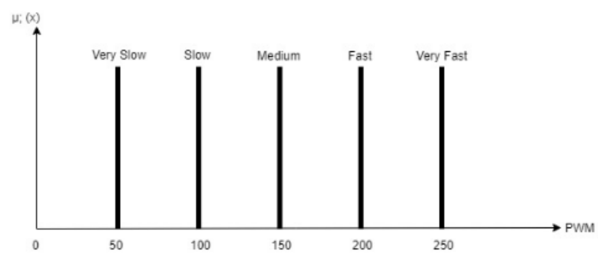


Figure 5. Output Membership Function

1st Process: Fuzzification

Fuzzification is a process of crisp input mapping from the controlled system into a fuzzy set according to its functions. The robot will figure out gas source based on 2 parameters, i.e., i) gas concentration data, namely: 60-140 (low), 60-220 (medium) and 140-220 (high); and ii) distance data, namely 10-40 (near), 10-70 (medium), and 40-70 (far). The linguistic variables for the input sensors are presented in Table 1. The defuzzification process is shown in equation (1)-(6). The membership functions of distance and gas fuzzy logic of equation (1)-(6) are shown in Figure 4. The robot could figure out the gas source based on the sensed gas concentration and the distance data. The inputs data of the fuzzy logic were used to control the PWM of the mobile robot (output). The linguistic variable for the output is shown in Table 2. The Membership function is shown in Figure 5.

2nd Process: Fuzzy Rules

The rules for the distance and fuzzy logic of this research are shown in Figure 6 and Figure 7. Each of fuzzy logic has 243 rules. The number of rules was obtained using the equation y^x, where y is the number of linguistic variable, and x is the number of the sensors used.

IOP Conf. Series: Journal of Physics: Conf. Series **1167** (2019) 012005 doi:10.1088/1742-6596/1167/1/012005

1. If (D1 is Near) and (D2 is Near) and (D3 is Near) and (D4 is Near) and (D5 is Near) then (LeftPWM is Slow)(RightPWM is Medium) (1)
2. If (D1 is Near) and (D2 is Near) and (D3 is Near) and (D4 is Near) and (D5 is Medium) then (LeftPWM is Medium)(RightPWM is Slow) (1)
3. If (D1 is Near) and (D2 is Near) and (D3 is Near) and (D4 is Near) and (D5 is Far) then (LeftPWM is Fast)(RightPWM is Slow) (1)
4. If (D1 is Near) and (D2 is Near) and (D3 is Near) and (D4 is Medium) and (D5 is Near) then (LeftPWM is Medium)(RightPWM is VerySlow) (1)
5. If (D1 is Near) and (D2 is Near) and (D3 is Near) and (D4 is Medium) and (D5 is Medium) then (LeftPWM is Medium)(RightPWM is Slow) (1)
6. If (D1 is Near) and (D2 is Near) and (D3 is Near) and (D4 is Medium) and (D5 is Far) then (LeftPWM is Fast)(RightPWM is Medium) (1)
7. If (D1 is Near) and (D2 is Near) and (D3 is Near) and (D4 is Far) and (D5 is Near) then (LeftPWM is Fast)(RightPWM is Slow) (1)
8. If (D1 is Near) and (D2 is Near) and (D3 is Near) and (D4 is Far) and (D5 is Medium) then (LeftPWM is Fast)(RightPWM is Medium) (1)
9. If (D1 is Near) and (D2 is Near) and (D3 is Near) and (D4 is Far) and (D5 is Far) then (LeftPWM is VeryFast)(RightPWM is VerySlow) (1)
10. If (D1 is Near) and (D2 is Near) and (D3 is Medium) and (D4 is Near) and (D5 is Near) then (LeftPWM is Medium)(RightPWM is Medium) (1)
11. If (D1 is Near) and (D2 is Near) and (D3 is Medium) and (D4 is Near) and (D5 is Medium) then (LeftPWM is Medium)(RightPWM is Medium) (1)
12. If (D1 is Near) and (D2 is Near) and (D3 is Medium) and (D4 is Near) and (D5 is Far) then (LeftPWM is Fast)(RightPWM is Medium) (1)
13. If (D1 is Near) and (D2 is Near) and (D3 is Medium) and (D4 is Medium) and (D5 is Near) then (LeftPWM is Fast)(RightPWM is Medium) (1)
14. If (D1 is Near) and (D2 is Near) and (D3 is Medium) and (D4 is Medium) and (D5 is Medium) then (LeftPWM is Fast)(RightPWM is Fast) (1)
15. If (D1 is Near) and (D2 is Near) and (D3 is Medium) and (D4 is Medium) and (D5 is Far) then (LeftPWM is VeryFast)(RightPWM is Fast) (1)

Figure 6. Fuzzy Rules Ultrasonic HC-SR04Sensor

1. If (G1 is Low) and (G2 is Low) and (G3 is Low) and (G4 is Low) and (G5 is Low) then (LeftPWM is Slow)(RightPWM is Medium) (1)
2. If (G1 is Low) and (G2 is Low) and (G3 is Low) and (G4 is Low) and (G5 is Medium) then (LeftPWM is Medium)(RightPWM is Slow) (1)
3. If (G1 is Low) and (G2 is Low) and (G3 is Low) and (G4 is Low) and (G5 is High) then (LeftPWM is CepatFast)(RightPWM is Slow) (1)
4. If (G1 is Low) and (G2 is Low) and (G3 is Low) and (G4 is Medium) and (G5 is Low) then (LeftPWM is Medium)(RightPWM is VerySlow) (1)
5. If (G1 is Low) and (G2 is Low) and (G3 is Low) and (G4 is Medium) and (G5 is Medium) then (LeftPWM is Medium)(RightPWM is Slow) (1)
6. If (G1 is Low) and (G2 is Low) and (G3 is Low) and (G4 is Medium) and (G5 is High) then (LeftPWM is CepatFast)(RightPWM is Medium) (1)
7. If (G1 is Low) and (G2 is Low) and (G3 is Low) and (G4 is High) and (G5 is Low) then (LeftPWM is CepatFast)(RightPWM is Slow) (1)
8. If (G1 is Low) and (G2 is Low) and (G3 is Low) and (G4 is High) and (G5 is Medium) then (LeftPWM is CepatFast)(RightPWM is Medium) (1)
9. If (G1 is Low) and (G2 is Low) and (G3 is Low) and (G4 is High) and (G5 is High) then (LeftPWM is VeryFast)(RightPWM is VerySlow) (1)
10. If (G1 is Low) and (G2 is Low) and (G3 is Medium) and (G4 is Low) and (G5 is Low) then (LeftPWM is Medium)(RightPWM is Medium) (1)
11. If (G1 is Low) and (G2 is Low) and (G3 is Medium) and (G4 is Low) and (G5 is Medium) then (LeftPWM is Medium)(RightPWM is Medium) (1)
12. If (G1 is Low) and (G2 is Low) and (G3 is Medium) and (G4 is Low) and (G5 is High) then (LeftPWM is CepatFast)(RightPWM is Medium) (1)
13. If (G1 is Low) and (G2 is Low) and (G3 is Medium) and (G4 is Medium) and (G5 is Low) then (LeftPWM is CepatFast)(RightPWM is Medium) (1)
14. If (G1 is Low) and (G2 is Low) and (G3 is Medium) and (G4 is Medium) and (G5 is Medium) then (LeftPWM is CepatFast)(RightPWM is Fast) (1)
15. If (G1 is Low) and (G2 is Low) and (G3 is Medium) and (G4 is Medium) and (G5 is High) then (LeftPWM is VeryFast)(RightPWM is Fast) (1)

Figure 7. *Fuzzy Rules* TGS 2600 Sensor

3rd Process: Defuzzification

Defuzzification step in this research used Sugeno method using AND operator by taking the minimum values of two sets. The output can be obtained using the equation (7)

$$Z = \frac{w1.\alpha 1 + w2.\alpha 2 + \cdots + wn.\alpha n}{\sum \alpha} \qquad (7)$$

Where Z is *defuzzification*, W is PWM motor, and α is *Fuzzy Rules point*

4. Results and Discussions

The experimental test was done using track with the distance length of ± 4 m to the gas source. The robot traversed the way and avoided the obstacle. The experimental testing situation is shown in Figure 8. Table 3 and Table 4 show the experimental data.

t = 2 s (moving to the right)

t = 9 s (moving to the left)

t = 14 s (moving to the right)

t = 18 s (moving to the left)

t = 24 s (moving to the left)

t = 30 s (moving to the left)

Figure 8. *Experimental Test Display*

Table 3. Experimental Result

Time (s)	Input										Output	
	Distance (cm)					Concentration (ppm)					PWM	
	D1	D2	D3	D4	D5	G1	G2	G3	G4	G5	Left	Right
2	27	126	125	26	19	86	88	141	93	96	226.63	174.46
9	17	17	57	120	57	81	82	130	87	91	137.86	245.00
14	32	96	129	20	19	78	81	127	84	88	228.13	177.50
18	30	46	95	107	26	76	79	125	83	87	198.65	232.43
24	22	144	87	39	40	75	76	120	81	84	175.00	206.25
30	36	38	41	63	37	142	152	165	128	99	194.77	235.46

Table 4. Measured and Calculated PWM output

Time (s)	Measured PWM Output		Calculated PWM Output			
			Distance Fuzzy Logic		Gas Fuzzy Logic	
	Left	Right	Left	Right	Left	Right
2	226.63	174.46	226.60	174.40	174.40	179.97
9	137.86	245.00	137.86	245.00	161.73	167.012
14	228.13	177.50	228.13	177.37	158.07	163.54
18	198.65	232.43	198.57	232.44	155.87	161.22
24	175.00	206.25	175.00	206.28	154.16	157.50
30	194.77	235.46	192.08	220.12	194.77	235.46

At the beginning of the searching (t=2s), the robot indicated the distance of the wall and did not detect the occurance of the gas. Thus, it moved to the left. This moving was caused by the distance sensor that detected an obstacle, not due to the gas sensor sensed the gas. It can be proved from the calculation of the PWM in the defuzzification process, whereas the calculated PWM of the left and the right sensor were 226.60 and 174.40 respectively. This calculation was the same with the measurement data, i.e., 226.63 and 174.46 for the left and the right PWM (Table 4). This situation continued until t=24s, in which the robot only detected the obstacles around it. The robot movement was suitable with the output of the fuzzy logic. It used the distance sensors data to navigate. It was successful to hint the obstacles and ran smoothly to the targetted gas. This movement changed into the gas fuzzy logic when it sensed the gas concentration was higher than its determined threshold, i.e. above 150 ppm. This situation happened in t=30s. By analyzing the calculation data, it can be seen that the obtained calculation PWM of gas fuzzy was the same with the PWM measurement, i.e., 194.77 and 235.46. It can also be proved that when the data in Table 3 is analyzed, it can be seen that the concentration gas was more than its threshold value, namely142, 152, 165, 128, and 99 for G1-G5 gas sensors. Therefore, the robot activated the gas fuzzy, not the distance fuzzy.

5. Conclusion

The distance and gas fuzzy logic have been successful implemented to the robot. It can switch the fuzzy algorithm based on the environmental situation. When it did not sense an enough gas concentration, it went forward and tried to search the possibility of the gas leakage location using its distance fuzzy. It changed its fuzzy algorithm activation when it sensed concentration above the determined threshold. In this situation, the gas fuzzy was activated. In its testing, the robot could accomplish its task well. It could avoid the obstacle, detect the gas, and find the gas leakage location.

6. References

[1] D. R. Wijaya, R. Sarno, and E. Zulaika, "Gas concentration analysis of resistive gas sensor array," *2016 Int. Symp. Electron. Smart Devices, ISESD 2016*, pp. 337–342, 2017.

[2] A. Shukla and H. Karki, "Application of robotics in onshore oil and gas industry-A review Part i," *Rob. Auton. Syst.*, vol. 75, pp. 490–507, 2016.

[3] N. L. Husni, A. Silvia, S. Nurmaini, and I. Yani, "Odor Localization Sub Tasks : A Survey," vol. 8, no. 3, 1843.

[4] T. Lochmatter, "Bio-Inspired and Probabilistic Algorithms for Distributed Odor Source Localization using Mobile Robots," vol. 4628, 2010.

[5] M. Rivai, Rendyansyah, and D. Purwanto, "Implementation of fuzzy logic control in robot arm for searching location of gas leak," *2015 Int. Semin. Intell. Technol. Its Appl.*, pp. 69–74, 2015.

[6] N. L. Husni and A. S. Handayani, "Odor Localizaton using Gas Sensor for Mobile Robot."

[7] A. Pandey, "Mobile Robot Navigation and Obstacle Avoidance Techniques: A Review," *Int. Robot. Autom. J.*, vol. 2, no. 3, pp. 1–12, 2017.

[8] W. Li, C. Yang, Y. Jiang, X. Liu, and C. Su, "Motion Planning for Omnidirectional Wheeled Mobile Robot by Potential Field Method," vol. 2017, 2017.

[9] F. Bounini, D. Gingras, H. Pollart, and D. Gruyer, "Modified artificial potential field method for online path planning applications," *2017 IEEE Intell. Veh. Symp.*, pp. 180–185, 2017.

[10] R. Lavrenov, F. Matsuno, and E. Magid, "Modified spline-based navigation: Guaranteed safety for obstacle avoidance," *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 10459 LNAI, pp. 123–133, 2017.

[11] A. Pandey, S. Kumar, K. Kant, and D. R. Parhi, "Mobile robot navigation in unknown static environments using ANFIS controller ☆," *Perspect. Sci.*, vol. 8, pp. 421–423, 2016.

[12] N. H. Singh, "Mobile Robot Navigation using Fuzzy Logic in Static Environments," *Procedia Comput. Sci.*, no. 125, pp. 11–17, 2018.

[13] S. N. Anual, M. F. Ibrahim, N. Ibrahim, A. Hussain, M. M. Mustafa, A. B. Huddin, and F. H. Hashim, "Ga-based optimisation of a lidar feedback autonomous mobile robot navigation

system," *Bull. Electr. Eng. Informatics*, vol. 7, no. 3, pp. 433–441, 2018.

[14] K. J. Miraswan, "Particle Swarm Optimization and Fuzzy Logic Control in Gas Leakage Detector Mobile Robot," pp. 150–155, 2015.

[15] L. Ran, Y. Zhang, Q. Zhang, and T. Yang, "Convolutional neural network-based robot navigation using uncalibrated spherical images," *Sensors (Switzerland)*, vol. 17, no. 6, pp. 1–18, 2017.

[16] P. Bartashevich, D. Koerte, and S. Mostaghim, "Energy-saving decision making for aerial swarms: PSO-based navigation in vector fields," *2017 IEEE Symp. Ser. Comput. Intell. SSCI 2017 - Proc.*, vol. 2018–January, pp. 1–8, 2018.

[17] V. Ganapathy, P. Sudhakara, T. T. Jia Jie, and S. Parasuraman, "Mobile Robot Navigation using Amended Ant Colony Optimization Algorithm," *Indian J. Sci. Technol.*, vol. 9, no. 45, 2016.

[18] A. M. Rao, K. Ramji, B. S. K. Sundara Siva Rao, V. Vasu, and C. Puneeth, "Navigation of non-holonomic mobile robot using neuro-fuzzy logic with integrated safe boundary algorithm," *Int. J. Autom. Comput.*, vol. 14, no. 3, pp. 285–294, 2017.

[19] P. K. Mohanty and D. R. Parhi, "A New Intelligent Motion Planning for Mobile Robot Navigation using Multiple Adaptive Neuro-Fuzzy Inference System," *Appl. Math. Inf. Sci.*, vol. 8, no. 5, pp. 2527–2535, 2014.

[20] and A. G. Ping Jiang, Yuzhen Wang, "Multi-variable Fuzzy Control Based Mobile Robot Odor Source Localization Via Semi- Multi-variable Fuzzy Control Based Mobile Robot Odor Source Localization Via Semi-tensor Product," *Hindawi Publ. Corp. Math. Probl. Eng. Vol. 2015, Artic. ID 736720, 10 pages http//dx.doi.org/10.1155/2015/736720*, vol. 2015, 2015.

Enhancement of Navigation Systems of Mobile Robots in Gas Leakage Searching

ORIGINALITY REPORT

8%

SIMILARITY INDEX

MATCH ALL SOURCES (ONLY SELECTED SOURCE PRINTED)

★doi.org Internet	5%

EXCLUDE QUOTES	ON	EXCLUDE MATCHES	OFF
EXCLUDE BIBLIOGRAPHY	ON		