A New Swarm Source Seeking Behavior based-on Pattern Recognition Approach

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***Abstract*—Recent advances in swarm robots have started making it feasible to deploy large numbers of inexpensive robots for odor localization tasks. However, coordination of swarm robots to accomplish such tasks remains a challenging problem. Due to this, there are uncertainties in the environment and in the robot itself. To make an easy and efficient swarm coordination strategy for odor localization tasks, distributed algorithm-based pattern recognition combined with swarm intelligent approach has been developed. A new simple algorithm of Fuzzy-Kohonen Networks and Particle Swarm Optimization (FKN-PSO) to achieve the odor source is presented in this paper. This paper demonstrates a group of real simple robots that are under fully distributed control can successfully search, track and find a real odor plume. The results were compared between FKN-PSO and Fuzzy-PSO to analyze the performance of the swarm robots in the process of localization. It was found that the proposed approach produces a simple algorithm, and it can solve the odor localization task more efficiently than Fuzzy-PSO. Moreover, it is suitable to be implemented on real robots to localize the source of odor in a short time, and the swarm robots have the ability for keeping formation in the group without collision.**

***Index Terms*—Swarm Robots; Odor Localization; Pattern Recognition; FKN-PSO.**

I. INTRODUCTION

In the research area of distributed tasks for swarm robots, the execution of several complex tasks has received much attention [1][2][3]. However, swarm robots must perform such tasks without a designated leader with limited physical, communication and power supply. Especially in odor localization tasks, it possesses the ability of the robots to move within their environment, to interact with other robots, to perceive the information of the environment and to process this information for localizing the odor source.

The solution of odor source localization is important in real time application, due to its practical significance for human security to search the sources of toxic gas leaks [4]. To search for a rational target location, the generated spatial robot models must be clear from the obstacles and attend all the optimizations criteria [5]. The problems that addresses the localization has been referred to as conventional control approach with simultaneous localization and mapping (SLAM) or concurrent mapping and localization (CML) [6,7,8]. However, the robot lacks a global positioning sensor and the algorithm produces difficult computational resources.

By using swarm robots, the control strategy in localization task must be in simple algorithm, due to the onboard sensing and processing [9]. Unfortunately, to accomplish such tasks in an unknown environment, it has to deal with the uncertainties in sensor detection, environment itself and error in actuator [10,11]. However, it is very complicated and highly nonlinear. Therefore, it would be difficult to estimate the spatial parameters using onboard sensors in order to determine the configuration relationships between the mobile robot and its immediate surroundings [10]. Therefore, there is a need to construct a control strategy [12,13].

Currently, the development of swarm robots algorithm for odor localization studies only prioritizes odor detection behavior, but it does not consider ways to control the swarm robots movement. Therefore, the travelling time for finding the source of odor will be slow. Further, the parameters used only affect the changes in the direction of swarm robots movement, as a result of changes in the distribution of odor [14]. Thus, the loss of the odor concentration detection can affect the overall performance of the robot performance. The loss of the source of odor can be due to the failure in sensor detection, resulting in robot motion control and environmental uncertainty.

Such problems become are important parameters in this paper. The proposed improvisation is combining the formation control with meta-heuristic approach and the route optimization. The useful meta-heuristics approach is combined into a fuzzy neural network named Fuzzy-Kohonen Network (FKN) to achieve the desired results. Meanwhile, to optimize the swarm robots route, FKN approach will be combined with particle swarm optimization (PSO) algorithm, that includes the possibility of sensor uncertainty in it. In this paper, the FKN-PSO algorithm is compared to Fuzzy-PSO algorithm to investigate the performance, especially in odor localization tasks.

II. SWARM ROBOTS LOCALIZATION

Generally, odor localization tasks using a group of agents can be divided into three subtasks: 1). *Plume Finding,* try to sense, because they have no contact with the plume; 2) *Plume Transversal,* try to maintain the swarm connection because they can sense the plume; 3). *Source Declaration,* declare the source of location when they found it [15,16]. By integrating all of the information collected by a group of agents, it can increase the efficiency of the odor localization. Some researchers have been successfully making the experiments using multiple robots [17,18] and swarm robots [19,20,21,22]. However, the application results have not reached to the best one, and the experiments are mostly done in simulation.

In recent years, some researchers have utilized PSO approach in managing the cooperation of swarm robots. The experiments showed that the PSO algorithm was successful in localizing odor sources [15,16,22,23]. However, PSO could not control the swarm robots movement. When they work in the changing environment with several obstacles, they can be trapped in local minima. To explore the environmental situations in the swarm robots localization, the PSO approach is combined with the FKN approach. The FKN is proposed to improve the swarm robots performance for achieving the target, and the PSO will be applied to follow the cues determined by the sensed gas distribution in an optimized way.

A. Localization Process

The process of localization involved five separate phases: i) searching the odor source, ii) follow the flume along concentration gradient, iii) tracking the odor plume, iv) searching for flume across the wind and finally, v) declaring the odor source. In this experiment, the plume finding was done in the simplest way. The robot did not move to search the target gas, until the sensor detected the gas concentration. The phases of their algorithm can be seen in Figure 1. Some developments and improvements were performed to achieve good performance. In this paper, the influence of the wind in terms of turbulence and instability wind in swarm robots environment was not discussed. If a robot senses the gas density, which is beyond a certain threshold value, it means that the gas source location is specified; hence, the searching behavior is terminated. Moreover, the searching is terminated if the swarm robots failed to localize the odor source by the maximum iteration.

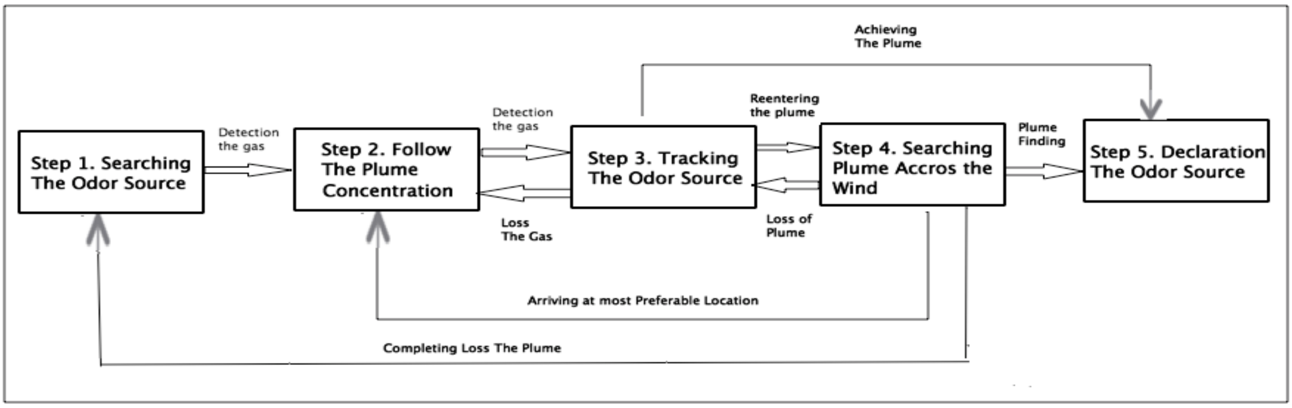


Figure 1: Odor Localization Process

Solving odor localization problems in dynamic environments requires hardware and software platforms. The essential problem is that the available odor sensors lack the combination of speed and sensitivity necessary to perceive the complex and dynamic structure of odor plume. The approach of moving slowly and continually sampling odor and flow data to reduce environmental noise is used in nature (starfish) and has been applied to robotic systems [24]. However, there are environmental constraints and significant plume sparseness or meander with time critical performance that can render these systems ineffective [24,25]. Therefore, to enhance the odor sensor performance, algorithm design has been implemented to achieve better result.

When a single robot wants to find an odor source, it should wander around to sample a series of odor concentration to find the densest place. If a group of robots dispersed within a broad range to sample the odor simultaneously, they can share the information of the concentration rapidly. The sample process becomes a spatial one, and the key point is information exchange among robots. In our previous research, two sensors TGS 2600 series were used for odor detection, three infra-red sensors were used for robots formation and X-bee communication for sharing the information with other robots [26,27].

B. FKN-PSO Design

In our previous research, The FKN algorithm was developed in a single robot [26]. However, in this research, FKN is combined with the PSO to detect the target in the swarm robots localization. The priority is the FKN algorithm, but it can switch each other in some environmental conditions, such as when 1) there is an obstacle, although the odor sensor is active; 2). the odor sensors loss the concentration or the odor concentration becomes low; 3) no obstacles is detected in the environment. The algorithm was selected because the swarm robots need a simple algorithm on onboard the sensor and processor. However, the efficiency and robustness results are still desired.

In this study, the robots are the n particles and they are moving in the search space X. The velocity of a particlev_{i} and the position of the particle is based on its previous position, x_{i}, and its velocity and position over a unit of time were computed as follows:

$$v_i^{k+1} = w_i * v_i^k + c_1 * r_1 * \left(p_i^k - x_i^k\right) + c_2 * r_2 * \left(p_g^k - x_i^k\right)$$
$$x(k+1) = x_{\mathrm{i}}(\mathrm{k}) + v_{\mathrm{i}}(\mathrm{k}+1) \quad (1)$$

where v_i^{k+1} and $x(k+1)$ represent the velocity and position of the k_{th}p article in the $i+1_{th}$ iterations. $c_1$and c_2 are uniformly distributed random numbers within $[0,c_1]$ and $[0,c_2]$. P_{best} and G_{best} are the best previous position of a particle and the best previous position in the swarms. A best previous position is where a particle obtains the minimum cost in its search history. The PSO algorithm is as shown in Figure. 2. Initially, all the robots will navigate on the environment by using the FKN algorithm. When one robot detects the presence of a source of odor, then the PSO algorithm will be activated. That robot will make the communication among the robots to share the information about the target coordinate and they move towards the odor source. The robot will track the concentration of odor value to the maximum threshold and then will stop moving when it is in the coverage area that has been determined as the source of the odor. To implement Equations (1) and (2) in the swarm robots, the pseudo code of local neighborhoods is as follows:

Step 1: Transfer target sensor codes to swarm robots.
Step 2: Initialize population with random positions and velocities
Step 3: Robots associated with a target based on the maximum gas concentration receive from each target and sensor target code
Step 4: Evaluate – compute fitness of each particle in swarm
Step 5: Do for each particle in each swarm {
Find particle best (*pbest*) – compute fitness of particle.
If current *pbest*<*pbest*
Pbest = current pbest
Pbest location = current location
Endif
Find position best (*gbest*) for the whole swarm
gbest position = position of min (all pbest in this swarm)
Update velocity of particle using Equation (1)
Update position of particle
Step 6: Repeat step 5 until termination condition is reached.

As investigated in our previous study, 12 patterns of obstacles configuration were assigned in the FKN algorithm [26]. In this paper, to make a simple process, only seven patterns of obstacles configuration were assigned to the FKN algorithm, as shown in Figure 2. Therefore, the swarm robots moved based-on the patterns and the speed control changed only in seven conditions [27].

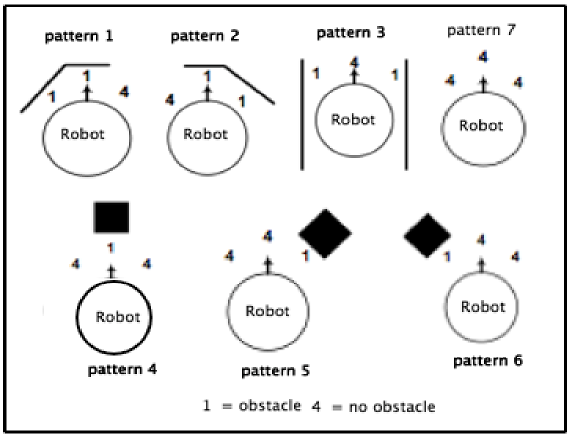


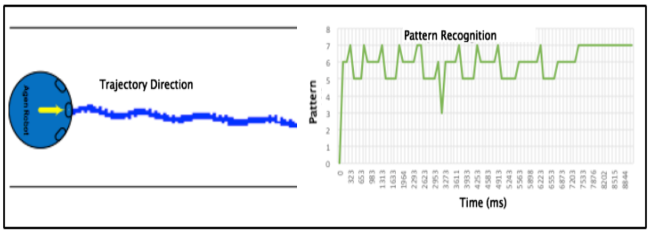
Figure 2: Seven of environmental patterns are assigned in FKN

Especially in pattern number 7, the PSO algorithm was activated. That strategy produced a simple algorithm, because the robots recognized the patterns using the rules base table with supervised learning strategies and the source of odor checking by PSO algorithm [26,27]. This information was used for connection between the seven patterns and speed of the motor. The output patterns of FKN were utilized to make the control decision for swarm robots to move in the recognized environment.

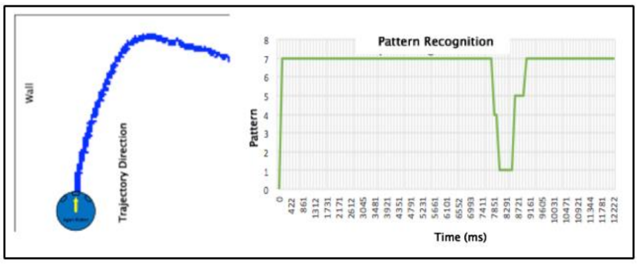
III. Experimental Results

There are four competencies of swarm robots for the localization tasks execution of the FKN algorithm: 1). to recognize the environmental patterns, 2). to communicate the odor source position to the whole swarm, 3). to converge in environments containing several shape obstacles and 4). to localize itself. The decentralized coordination with the FKN algorithm was used to synthesize shapes of an environmental pattern, instead of restricting our environment. To investigate the feasibility of the proposed algorithm, some experiments were conducted using three small robots with three infra-red sensors and two gas sensors in it.

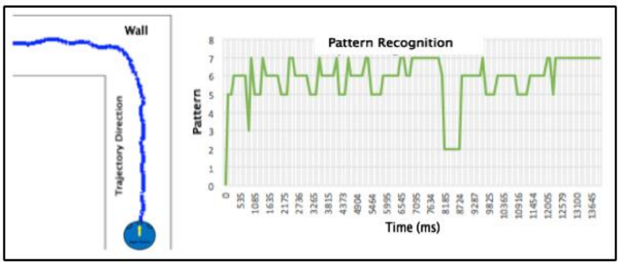
The results in Figure 3 show that the swarm robots have the ability to synthesize and to recognize several obstacle patterns shape in real environments, as shown in Figure 4 (a)–(c), for robot 1(R1), robot 2 (R2) and robot 3 (R3) respectively. Figures 4 also describes some patterns output from three sample of environments including the corridor, turn right and turn left with corridor respectively. The results show that the robot had the ability to recognize the three patterns, move in safe condition and keep the distance from the wall.



(a) Corridor



(b) turn right



(c) turn left with corridor

Figure 3: Environmental Recognition-based FKN algorithm

TGS 2600 as an odor sensor was tested by using chemical formula CH3OH or methanol. To know the response of the sensor, the artificial odor in form of a hermetically closed box, where a known increasing amount of methanol was utilized. A fan was included to accelerate methanol vaporization and homogeneous dispersion. The calibration was performed to determine the threshold value of the coverage area of the odor sensor. From the experiment, the characteristic of odor sensor in several distances is as shown in Figure 4. The sensor was set-up in two interval values, such as the minimum value at 40 decimal and the maximum value at 80 decimal. The threshold value indicated that the response of odor concentration is dependent on the distance between sensor and the source of odor.

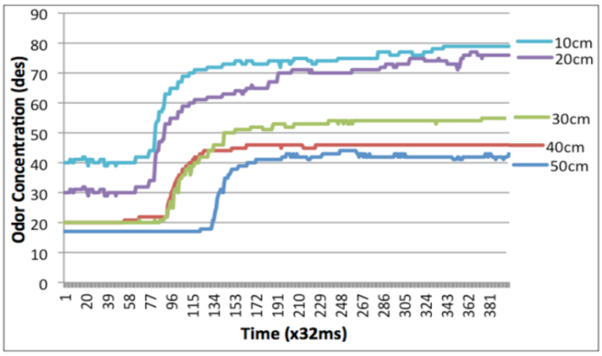
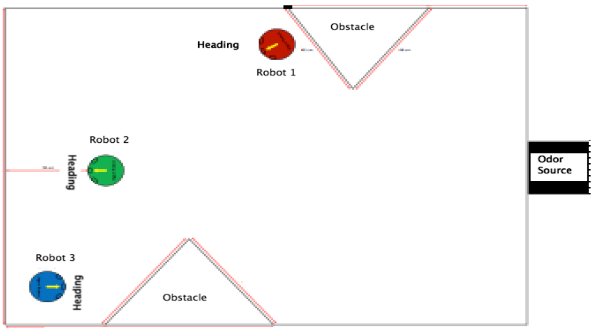
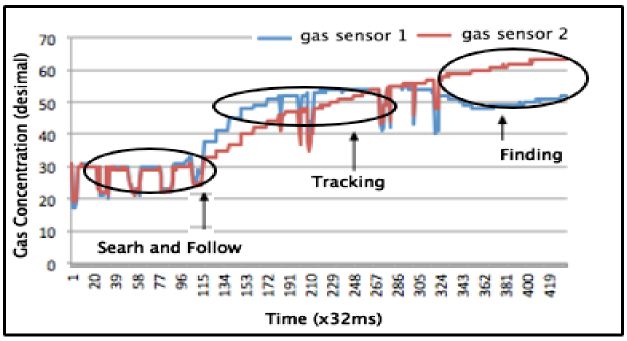


Figure 4: Odor Concentrations-based TGS 2600 sensor

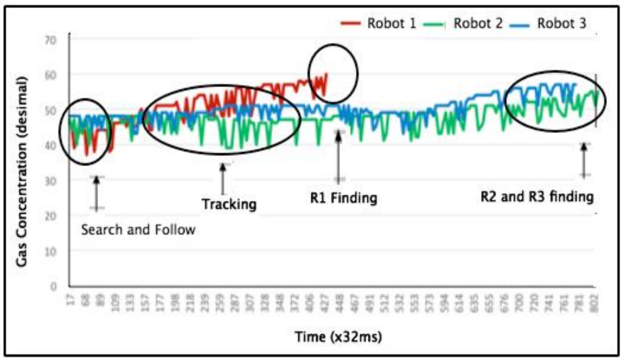
The localization experiments were conducted in indoor laboratory without the influence of the wind. As presented in Figure 5 (a)–(d), the odor localization process went through several stages, the initial position of the robots that spread out and the random direction from the source of the artificial odor. The robots moved in divergent to search the source of the odor and successfully tracked the source of the gas leak. However, to avoid the obstacles that exist in the environment was still a priority task.



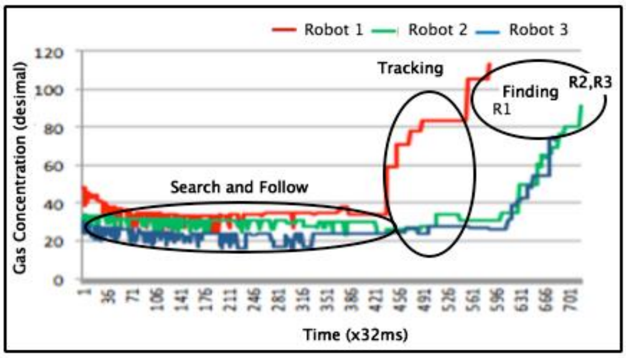
(a) Simple of environment with two obstacles



(b) Single robot based on FKN-PSO



(c) Three robots based on FKN-PSO



(d) Three robots based on Fuzzy-PSO

Figure 5: Comparison of odor localization process in simple environment

During the localization process, all the robots have the ability to recognize all patterns that were assigned in the FKN algorithm. Particularly, when the pattern number 7 was detected by the swarm robots, this condition activated the PSO algorithm, due to the condition that without obstacles all robots search the odor concentration. If one robot detects the presence of the odor concentration, and it will be share the information to all robots in the group and they move to find the target quickly.

By using FKN-PSO algorithm, the swarm robots found the odor source faster as the robots were able to recognize the environmental situation. Thus, the swarm robots directly executed the target. From the localization process, in the sample environment in Figure 5 (a), the odor detection by the sensor at robot 1 (R1) was about 3 sec, and the time travelled to find the target was about 14 sec. The other robots R2 and R3 followed the target within 24 sec and 26 sec respectively. However by using Fuzzy-PSO, Robot 1 (R1) took about 14 sec to find the target: The searching process took a very long time, but faster when tracking the odor source, which was about 20 sec. Because the robots must access every rules in the fuzzy process, the number of rules utilized in the Fuzzy-PSO algorithm is about 27 rules, but there were only 7 rules in FKN-PSO. Hence, this process increased the time to find the target and the computational resources. In the process of localization, three stages were used to find the source of odor, which are searching, tracking, and finding and declaring the odor source. From the localization process in Figure 5, using the FKN-PSO gave good performance as compared with the Fuzzy-PSO. In visualization, the trajectory of swarm robots when they moved to the target is as shown in Figure 6.

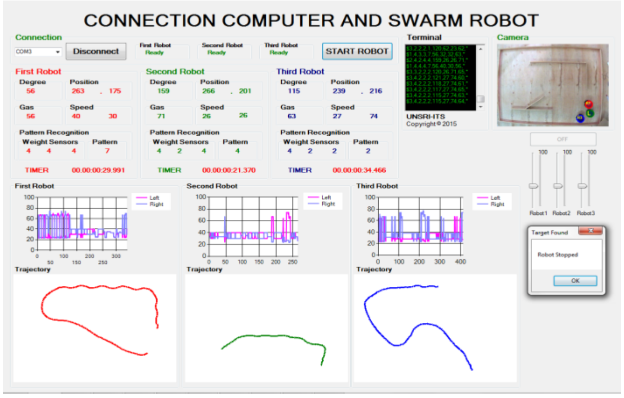


Figure 6: Swarm robots movement to find the target

All experiments showed that the swarm robots successfully performed the localization process, and the odor source could be determined in a short time without any collision with the other robots and obstacles. A summary of the experimental results is shown in Table 1.

Table 1
Comparison of Swarm robots performance

Description	Fuzzy-PSO	FKN-PSO
Time to search the odor/first detection	1.0 – 14.0 sec	2.0 – 3.0 sec
Time to track the odor	14.0 – 20.0 sec	3.0 – 14.0 sec
Time to find the odor	19.0 sec	14.0 sec
Number of Rules	27 rules	7.0 rules
Resources	60 kbytes	43 kbytes
Time to process the localization with three robots	65.0 sec	63.0 sec

Based on the results in Table 1, the total time for localization was almost the same between FKN-PSO and Fuzzy-PSO. However, by using Fuzzy-PSO, the swarm robots were very slow in searching the concentration of odor in the environment. If the concentration odor was detected, they tool faster time to track as compared to the time taken by FKN-PSO to find the source of odor. In the future, the wind instability and turbulence will become two important parameters to determine the swarm robots performance. The FKN-PSO with seven environmental patterns generated a satisfactory performance to recognize the environment, to avoid the obstacle and always move in the group, and to find the odor source, with simple algorithm. Pattern recognition approach is a promising technique to be developed further for solving the location task of swarm robots.

IV. Conclusion and Future Work

This paper has presented a pattern recognition with optimization approach for keeping the swarm robots in a group when they localize and find the odor source. The process based on real-time sensory information has been successfully implemented on three simple mobile robots. Each robot has three infra-red sensors for pattern recognition task and two odor sensors for target detection task. Hence, optimization of the prototype-environmental mapping becomes important role in the proposed algorithm. When they explored the environment to perform the localization, they explicit coordination allowing the robots to successfully navigate and move to the odor source. In this research, Fuzzy-PSO becomes a benchmark for comparing the performance of the swarm robots. By using FKN-PSO approach, the computational resource was reduced and this enhanced the process localization performance. Many aspects of this method are worth further investigation in the future. Although the present design can cope with moving swarm robots as well as stationary obstacles, more accurate perception sensors are required for more complex environmental configurations.

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