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Cooperative Searching Strategy for Swarm Robot

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***Abstract*—This paper represents a cooperative searching strategy of swarm robot in finding and localizing odor source. 3 robots, namely: Cyborg G11, Cyborg G12, and Cyborg G13 were used as agents that form the swarm in this research. The cooperation among the robots trough communication has shown the success of the swarm in odor searching. When one of the agents in swarm robot detected a high concentration of odor in its place, it will use the data of this concentration as its own information in order to decide what position it should go. Moreover, this data was also shared to the other robot trough wireless communication such that they can compare their own data with the data shared to them. By having the information, each agent can decide what solution they should take. The experimental work in this research shows that using communication among the robot can support the robots in searching and finding the odor source.**

***Keywords*—communication; cooperative searching strategy; PSO; swarm robot; X Bee.**

I. Introduction

Since a single robot implementation cannot fulfill the human satisfaction due to the increasing of task requirements, many scientists developed multi robots to accomplish a complicated task, either in the homogenous [1], [2] or heterogeneous [3] [4], [5], [6] forms. For the homogenous forms, researchers usually used a group of autonomous robots that solves a problem using a distributed approach. These robots are usually called as a swarm robot. Swarm has been applied in a variety of tasks, such as: aggregation, flocking, foraging, object clustering and sorting, navigation, path formation, deployment, collaborative manipulation and task allocation problems [7]. In other word, a swarm employs some simple agents to perform different types of tasks to reach the target

In its application, the individual agents of swarm are not informed about the global status of the colony [8]. There is no leader that guides all of individual agents of swarm to reach their goals. The knowledge of the swarm is distributed throughout all the agents. The goal will only be able to be reached by using cooperative behavior among individual agents. Thus, the individuals will not be able to accomplish their tasks without the help or interaction of the individuals with the other agents.

In accomplishing odor localization tasks, swarm robots should have a special skill for moving in their environment, interacting with other robots, perceiving and processing the information of their environments [9]. The swarm shares information about the environment and the individual agents interact with each other, therefore a distinction between the sensing and the communication network is made [10]. Due to no central coordination within their task execution, their cooperative behavior becomes an essential part in swarm research. The effectiveness of the coordination among the individual agents of swarm can be achieved using information sharing. This information sharing can reduce the duration of time searching.

To control robots through communication is not an easy way. There are some factors should be paid attention [11], such as: communication architecture, the amount of computation, and communication bandwidth [12]. Therefore, some researchers develop distributed robotic sensor network in order to achieve a robust communication with low computation and low communication burden [13], [14], [15]. This paper applies a distributed robotic system in order to achieve a good communication performance in searching, tracking, and finding odor source.

II. Searching Strategy

A. Definition

Searching strategy is defined as algorithm that manages the interactions among individual agent to its environment and to other agents in swarm robots through communication. The use of this communication will improve the effectiveness of target searching task. In this research, the target of the searching is odor. This odor searching has a tight correlation with the odor localization. In odor localization, there are 3 steps that should be accomplished by the robots, such as plume finding, plume tracking and plume declaration. This research only focuses on the plume tracking where the robot has already been in the coverage area of plume dispersion. The searching strategy was applied in order to track the source of the odor. The cooperation of individual agents in this research was analyzed to see the effectiveness of the communication among the systems.

In this research, swarm robot behavior was managed by an X-bee wireless communication. This wireless communication

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gathers and communicates all information and data related to the swarm. In uncertain environment, the main purpose of cooperative searching strategy using wireless communication is to let the robot to coordinate the position of the searching target. When a robot has sensed a high concentration of the odor source, it will send the information to the server. The server then continued to transmit the information got from this robot to the other robots. In this research, 3 robots were used. Each of the robots in the swarm has a chance to be a leader. It depends on the concentration that it senses. When it senses higher concentration more than the stated threshold concentration and higher than the other two robots, it may claim that it has found the source and may become the leader. The follower robot (other 2 robots) only followed this temporary leader robot that is closer enough to the odor source.

B. *Algorithm*

In this research, a Fuzzy logic and Particle Swarm Optimization (PSO) were used to decide which trajectory to take and to optimize the searching strategy of swarm robot in localizing odor sources. Fuzzy logic was used as the artificial intelligence of robots when they meet obstacles. Two behavior based of robots were implemented using this fuzzy logic, such as wall following and obstacles avoidance. Although fuzzy logic is a part of this research, however, in this paper it will not be discussed. It is due to fuzzy logic does not include in the communication established among the agents of the swarm discussed in this paper. The fuzzy logic only relates to each individual agent in the swarm. It manages the individual behavior of the agents in following the wall and avoiding the obstacles. The information of the wall or the obstacles met by the agents and what decision made by the agents will not be shared to the other agent trough communication. The decision made by the agents depends on the individual agents themselves. Therefore, this fuzzy logic was not discussed in this paper.

In this research, the process of PSO algorithm was begun with an initialization of a group of random agents, *N*. These agents are usually called as particle in PSO algorithm. Based on its position, the *ith* particle in this research was recognized as a point in an experimental space that the robots can occupy. Each particle tried to optimize its fitness function by considering the information from itself or from other particles among its group of swarm. The information was got during its exploration in searching space. The fitness function value determined the decision taken. In odor localization application, the fitness function is got from the odor concentration detected by the robot. The higher the fitness function value (higher concentration) means that the closer the particle to the final solution (in this case to the source). Therefore, the particles should be directed to keep in the track of its best position. Each particle should follow the track points by comparing current position to its next position until it achieved the final solution. The best position got by particle in its each track is called local best (lbest) or personal best (pbest). From this explanation, it is really clear that the communication of each particle to other particles is really necessary in order to get its personal best position. Besides personal best, the success of swarm trajectory in target searching is also influenced by the global best (gbest). A global best is the position with highest value among all the personal best. A global best can be achieved by each particle by having communication about each personal best position among particles in the swarm.

III. Experimental Setup

In this research, swarm robot consists of 3 agents, namely: Cyborg-G11 (Blue Agent), Cyborg-G12 (Yellow agent), and Cyborg-G13 (Green Agent). These 3 robots were designed to do odor localization task. A cyborg-G1x is a cylindrical robot with diameter 15 cm. It has 3 and half layers. In the first layer, there are 4 DC motors 12 v as the wheels mover. In the bottom of second layer, there are 2 DC motor drivers, L298D and one DC converter that will convert the 12 v battery supply to 5 v voltage as the input of other components, such as sensors and microcontrollers. On the top of second layer, there are Arduino ATmega 2560 and 3 ultrasonic sensors SRF04. At the bottom of third layer, there is Raspberry pi3 type B while on the top, there are X-bee Pro S2, TGS 2600, TGS 2602, and TGS 2620, and a compasss HMC5883. Finally, on the half of uppermost layer, there is an LCD as the display of the gas concentration, position, and type of the gas sensed by the robots. The physical shape of the Cyborg-G1x can be seen in Fig. 1.

In this research, the relation between updated velocity and its personal best and global best was represented using equation (1), as follows [16]:

$$v_i^{t+1} = w_i(v_i^t + c_1.Rand().(p_i^t - x_i^t) + c_2.rand()(p_g^t - x_i^t)) \quad (1)$$

While each particle updated its position using the equation (2):

$$x_i^{t+1} = x_i^t + v_i^{t+1} \quad (2)$$

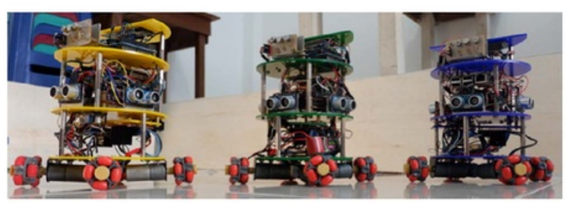

Fig. 1. 3 Agents used as swarm robot, Cyborg-G11, Cyborg-G12, and Cyborg-G13

The description of parameters used in equation (1) and (2) can be seen in Table I. The value of w is extremely important to ensure convergent behavior, and to optimally tradeoff exploration and exploitation [17]. The flowchart of algorithm in this research can be seen in fig. 2 and the pseudocode of the PSO can be seen in Fig. 3.

TABLE I. DESCRIPTION OF PARAMETERS USED IN PSO ALGORITHM BASED ON EQUATION (2) AND (3)

Parameters	Desciption
x_i^t	Current position $x_i^t = x_{i1}, x_{i2}, x_{i3}, \ldots\ldots, x_{i1n}$
x_i^{t+1}	Updated position
v_i^t	Current velocity $v_i^t = v_{i1}, v_{i2}, v_{i3}, \ldots\ldots, v_{i1n}$
v_i^{t+1}	Updated velocity
p_i^t	Best local position relates to highest concentration that a particle got from its own or other particles' information. $p_i^t = p_{i1}, p_{i2}, p_{i3}, \ldots\ldots, p_{in}$
p_g^t	Best global position relates to highest concentration that a particle got from the pbest information. $p_g^t = p_{g1}, p_{g2}, p_{g3}, \ldots\ldots, p_{gn}$
w_i	Inertia weight that has function to improve the drawback of prior velocity occur on the current velocity [18]
c_1 and c_2	two positive constants, learning factors [17].
$Rand()$ and $rand()$	two random generator functions, the return value are between 0 and 1 [16] .

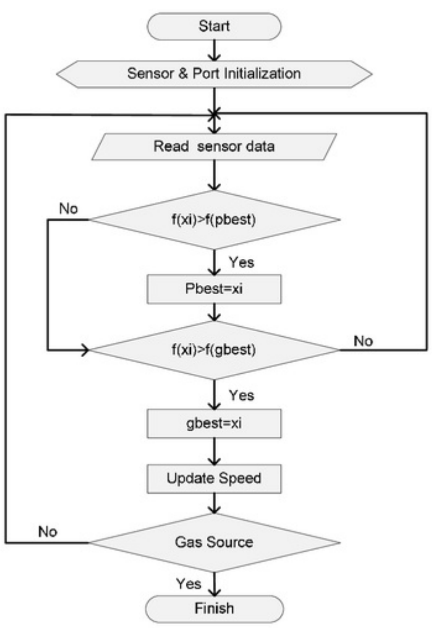

Fig. 2. Flowchart of PSO algorithm

```
For each particle
{
   Initialize particle
}

Do until maximum iterations or minimum error criteria
{
   For each particle
   {
      Calculate Data fitness value
      If the fitness value is better than pBest
      {
         Set pBest = current fitness value
      }
      If pBest is better than gBest
      {
         Set gBest = pBest
      }
   }

   For each particle
   {
      Calculate particle Velocity
      Use equation (1) and (2)
   }
```

Fig. 3. Pseudo code of PSO algorithm

As stated before, communication is the most important aspect of swarm robots. Using this communication, every individuals of swarm can share information. An X-Bee wireless module with 2.4 GHz frequency, a range of approximately 90 m indoor and power transmitted 50 mW (17 dBm) was used in this research. This communication module can relate a robot to other robots and to the server. The block diagram of communication relationship can be seen in Fig. 4.

The purpose of using camera in this experiment is to make easy the coordination among the swarm agents. This camera has function to show the position of each robot.

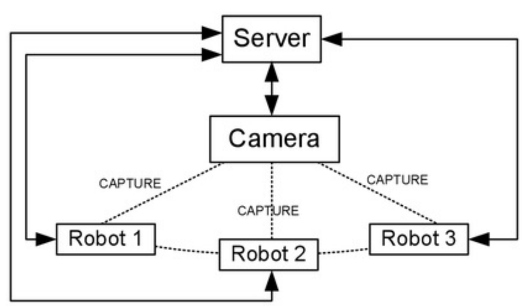

Fig. 4. The block diagram of coordination among the

It was mounted on the top of the expetimental area. A pi camera type was used in this experiment. A Hue Saturation Value (HSV) model was applied to this camera in order to filter the colors of the robots so that they can still work although their colours are not Red, Green, and Blue. The camera mounted on the top of the experimental work can be seen in Fig. 5.

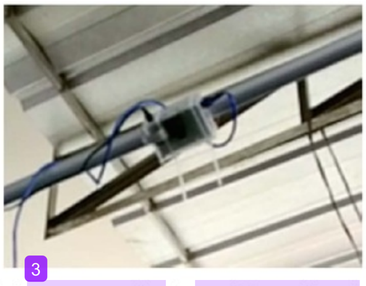

Fig. 5. A camera mounted on the top of the experimental work.

A pi camera that was used in this research (Fig. 5) has task to monitor and take the picture of the robots. The data that the camera got was then transmitted to the server. The data was then transmitted by the server to the raspberry that is embedded to the robot. Then, the raspberry, as the mini computer in this experiment, will process the data. In the experimental work, the computer used has been inputted a coding to activate the camera detection. Thus, when the camera detected and found the robot, the next process is determining the position of each robots using the coordination between server and the raspberry. This raspberry does the image processing and determine the coordinate x and y of each robot based on the colors. The x and y data as the robot position coordinates is then sent to the server using LAN network.

IV. Result and discussion

A real experiment was conducted in 2 x 2 m room. This scaled room is necessary to achieve a valid data. Working with a gas sensor is a quite complicated. The characteristic of odor that can easily disperse limit the area of experiment. Three agents were deployed to the searching area. One odor source consist of ethanol was placed in one of the side of experimental area. Each of the robot can share information about the concentration in order to get its pbest and gbest. When a robot found a best position, it will share the location information to the others. The other robot will update its velocity and position and follow the robot with its best position. This action will continue until a convergence of the algorithm achieved.

At the beginning of the deployment, all of the agents were placed in different position. The position of Cyborg-G11 was at the coordinate 20,10; Cyborg-G12 was 22,165.; and Cyborg-G13 was 215,12 (See Fig. 6). In the first 30 second, every agents started to find the source. Each of them moved randomly and searched best position by using its local and global knowledge trough communication among them.

Fig. 6. Initial position of the robots and odor source. Each of them were placed in different side.

In this situation, G11 moved to 15,12; G12 22,155; and G13 in the position 210,11. Their positions can be seen in Fig. 7

When G11 got minimum position to the source, it informed its position to G12 and G13 using X Bee communication. G13 that stayed in the position 140,12 at t=180 s, started to move to G11 with a new position at 210, 140 at t =210 s. It continued to get really closer to G11 that has new position at 190,165. It also happened to G12, trough the communication, it got position at 110,165 (Fig. 10).

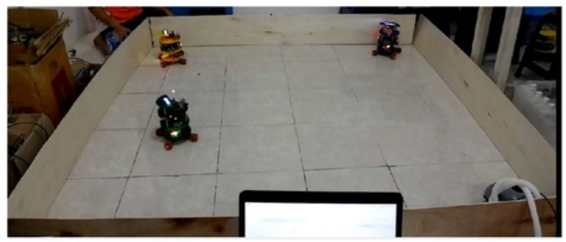

Fig. 7. Swarm robots' position in the first 30 second.

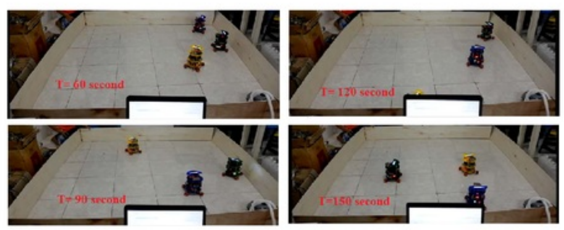

Fig. 8. All of the agents still searched the minimum position to the source.

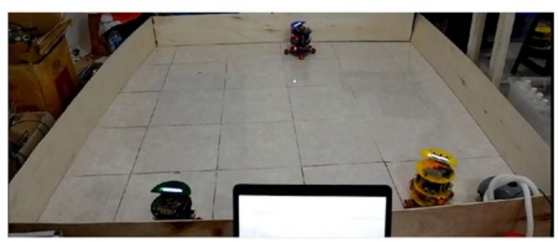

Fig. 9. G11 has found the minimum position of the gas at t = 180 s.

Fig. 10. G13 followed the G11 that has got best position at t=210 s

Fig. 11. G12 also came to gather to other agents after got information from its surrounding and from G11 and G13.

TABLE II. SIGNAL STRENGTH OF INDIVIDUAL ROBOTS TO THE SERVER

TIME (S)	Signal Strength (dBm)			Time Delay for Sending Data (s)		
	G11 to Server	G12 to server	G13 to server	Server to G11	Server to G12	Server to G13
30	-56	-48	-57	3.5	3.1	3.5
60	-58	-50	-56	3.6	3.2	3.5
120	-50	-54	-58	3.2	3.4	3.6
180	-52	-52	-51	3.3	3.3	3.3
210	-52	-52	-52	3.3	3.3	3.3
240	-52	-52	-52	3.3	3.3	3.3

At the last second, G12 that stayed at coordinate 110,165 started to follow the G11 and G13 that already got their best position. It ran until it arrived at coordinate 193,16. Fig. 11 showed the situation when every agents came together near the source location.

The signal strength of the communication is presented in Table II. As shown in Table II at first 30 second, each robot stayed at the opposite position with a same distance, the signal strength value is almost the same, i.e. between -48 until -57 dBm. The signal strength changed with the change of the distance among the robots to the server. Due to the experimental environment was not so large, the signal strength had almost the same value. It also happened to the time needed by the server to send the data to each robots. The rate of the time delay is between 3.3 until 3.6 s. However, the system has run well, the cooperation among the robots has been achieved and the target could be found. The area in this research is only 2 x 2 m due to the target searching was a gas that has charateristic easily to be dispersed. Thus, to overcome the dispersion uncertainty, the experimental area was limited only to 2 x 2 m.

V. CONCLUSION

In this research, one of the factors that support the success of the experiment were the communication among the individual robots of swarm. The research result shows that the communication support the success of the odor searching and finding. The cooperation of the individuals robots trough communication can increase the performance of the swarm. Howeve, in this research, some difficulties occured, such as unstability of the environment that disturbed the result of the experiment. One of them is the odor characteristic that disperse easily due to wind or other effect of environment internally or externally. The wind that can change easily causes difficulties in odor experiment. Some times, the agent will lost contact to the odor and it forces it to start the odor searching from the beginning. This process is not so easily, due to it need more time to finally find the source. However, the approach proposed in this research showed a great success. The method has been successful accomplishing odor searching task. The communication among agents in the swarm supported the success of odor searching task.

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