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Comparative Analysis Multi-Robot Formation Control Modeling Using Fuzzy Logic Type 2 – Particle Swarm Optimization

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ABSTRACT

Multi-robot is a robotic system consisting of several robots that are interconnected and can communicate and collaborate with each other to complete a goal. With physical similarities, they have two controlled wheels and one free wheel that moves at the same speed. In this Problem, there is a main problem remaining in controlling the movement of the multi robot formation in searching the target. It occurs because the robots have to create dynamic geometric shapes towards the target. In its movement, it requires a control system in order to move the position as desired. For multi-robot movement formations, they have their own predetermined trajectories which are relatively constant in varying speeds and accelerations even in sudden stops. Based on these weaknesses, the robots must be able to avoid obstacles and reach the target. This research used Fuzzy Logic type 2 – Particle Swarm Optimization algorithm which was compared with Fuzzy Logic type 2 – Modified Particle Swarm Optimization and Fuzzy Logic type 2 – Dynamic Particle Swarm Optimization**.** Based on the experiments that had been carried out in each environment, it was found that Fuzzy Logic type 2 **-** Modified Particle Swarm Optimization had better iteration, time and resource and also smoother robot movement than Fuzzy Logic type 2 – Particle Swarm Optimization and Fuzzy Logic Type 2 **-** Dynamic Particle Swarm Optimization**.**

Keywords: Multi-robot, Fuzzy Logic Type 2, Particle Swarm Optimization, Modified Particle Swarm Optimization, Dynamic Particle Swarm Optimization

1. INTRODUCTION

The advantages of multi-robot systems compared to individual robotic systems include high flexibility and resilience, those kind of characteristic will produce good adaptability to their environment because obstacles can be set anywhere and environmental changes are always there [1][2][3]. However, to control the multi-robot formations in order to search and follow the target is the main problem, because it has to create dynamic geometric shapes towards the target [4]. An iterative optimization approach for a multi-robot system in an obstacle environment. The proposed approach obtains optimal pattern parameters, then iteratively sets goals and plans a collision-free path for each robot to reach the destination position [5].

Referring to the literature, various approaches for controller and strategy on multi-robot formation is iterative optimization approaches for multi-robot system in obstacle environment which has a function to achieve optimal pattern parameter. Futhermore, it can iteratively set target and plan a collision free trajectory on multi robot to reach the target [6], another one movement controller used is called PID (proportional

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integral derivative) controllers [7]. In its movement requires a control system in order to move the position as desired. For kinematic modeling, wheeled mobile robots are nonlinear, so the Fuzzy logic method is generally used to facilitate controller design.

Fuzzy logic has been widely used to solve problems of uncertainty, inaccuracy and carelessness in group robotics systems [8]. However, the fuzzy logic type-1 (SLFT1) system does not produce a good response in unstructured and dynamic environmental conditions [9]. The development of SLFT1 into a type-2 fuzzy logic system (SLFT2) improves the ability of the control system on the swarm robot in terms of formation control [10][11]. This is because of the improvement in controller performance by including the uncertainty interval in the fuzzy membership function, both input and output of the fuzzy logic system. Unfortunately, computing is increasing and the swarm robot does not have a target achievement control system or route optimization yet.

The control system on the swarm robot, must calculate the short time, fast process, simple algorithm, but still able to maintain formation and avoid collisions at the same time [12][13][14]. There are a lot of methods that have been used to fulfill these parameters, including the path planning method, artificial potential function and potential field [15][16][17]. Unfortunately this method relies on the built environment map, if the environmental conditions change, the robot will fail. Another method is the use of swarm intelligence, which shows satisfactory results, because it uses the characteristics of animals in nature in searching for food, including Particle Swarm Optimization (PSO) [18][19][20]. Unfortunately, many applications of PSO methods for target route search optimization, often result in partially optimal performance, and can degrade formation control performance. So it needs a PSO method that can react dynamically in uncertain conditions.

From the various background problems that have been discussed, what is proposed in this research is how to improve the performance of the multi-robot formation control system in order to produce good performance in terms of movement to avoid obstacles and route optimization. Hopefully, the proposed of the new strategies and mechanisms can give a contribution to robotics control system research in the case of formation control in multi-robot systems.

2. MATERIALS AND METHODS

In this study, have kinematic model multi-robot and using the fuzzy logic type 2 - PSO method is compared with the fuzzy logic type 2 - MPSO and the fuzzy logic type 2 - DPSO. Where the fuzzy logic type 2 is to control the walking robot and PSO, MPSO, DPSO are to find targets. Process detail on each of the stages described in the following subsection:

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2.1 KINEMATIC MODEL ON MULTI ROBOT

Declared as a kinematic controller because it consists of the transformation of the Cartesian space to the joint space. The controller requires feedback in the form of coordinates. [21][22][23]. This study uses a mobile robot that has two right and left wheels with separate steering (differentially driven mobile robot, abbreviated DDMR), as illustrated in Figure 1.

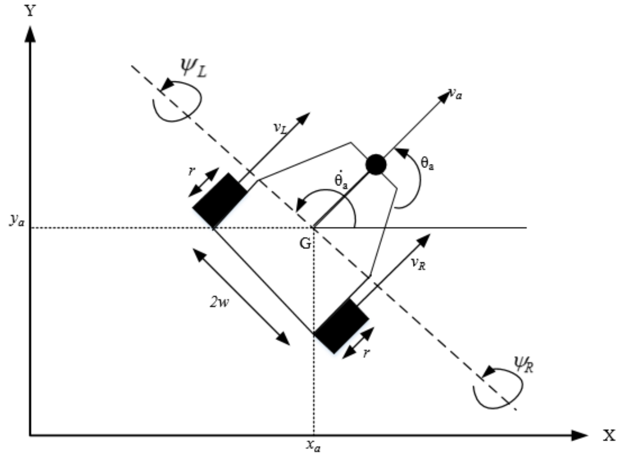

FIGURE 1. Nonholonomik mobile robot

Based on Figure 1 the width of the mobile robot is 2w and r is the radius of the wheel. The global coordinates are denoted by (X, Y), and the local coordinates centered on the robot are denoted (x_a, y_a). The center point of the local coordinates is at the robot's center point (G) with coordinates (x, y). The point of view of the robot is denoted θ_a. The linear speed of the robot is denoted va. The kinematic model of the robot is obtained according to the following equation:

$$\begin{bmatrix} \dot{x}_a \\ \dot{y}_a \\ \dot{\theta}_a \end{bmatrix} = \begin{bmatrix} \cos\theta(t) & 0 \\ \sin\theta(t) & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v_a \\ \omega \end{bmatrix} \tag{1}$$

From Figure 1 it is assumed at xy cartesian coordinates. The speed of the right wheel (v_R) and the left wheel (v_L) of the robot is obtained from the velocity equation v_a added to half of the width of the robot and the rotational displacement of the wheel angle $\dot{\theta}$. so that the speed of the left and right wheels is described in the following equation:

$$v_R = v_a + b\dot{\theta}_a \tag{2}$$

$$v_L = v_a - b\dot{\theta}_a \tag{3}$$

By substituting equation (2) and equation (3), we get the equation for the linear velocity of the robot v_a and the equation for the angular robot $\dot{\theta}_a$ as follows:

$$v_R + v_L = 2v_a$$

$$v_a = \frac{1}{2}(v_R) + v_L \tag{4}$$

$$v_R - v_L = 2b\dot{\theta}_a$$

$$\dot{\theta}_a = \frac{v_R - v_L}{2b} \tag{5}$$

Based on Equations (2) and (3), substituting Equations (4) and (5) into Equations (1), we get

$$\begin{bmatrix} \dot{x}_a \\ \dot{y}_a \\ \dot{\theta}_a \end{bmatrix} = \begin{bmatrix} \frac{r}{2}\cos\theta & \frac{r}{2}\cos\theta \\ \frac{r}{2}\sin\theta & \frac{r}{2}\sin\theta \\ \frac{r}{2b} & -\frac{r}{2b} \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} \tag{6}$$

Then, modeling is used as the basis for software creation. In this research, 4 (four) mobile robots were used, called robot 1, robot 2, robot 3, and robot 4. The formation of the multi robot system is as follows:

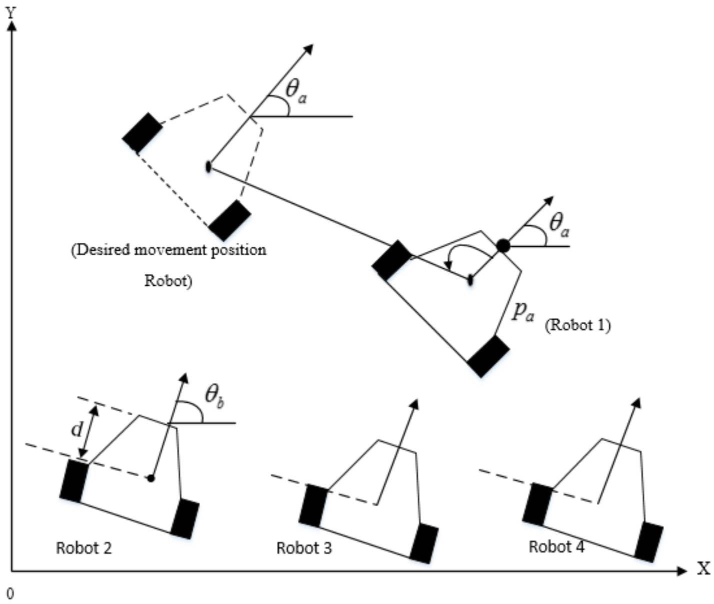

FIGURE 2. Multi-robot System Formation Model

2.2 CONTROLLER DESIGN

In this subsection, two controllers are designed, namely the Target Seeking controller and the Obstacle avoidance controller. The controller looks for the target using the PSO (Particle Swarm Optimization) controller and the controller avoids the obstacle using type 2 fuzzy logic.

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The function used in this research is the Gaussian membership function. The input values from the user, which are σ and c will form the set of Gaussian membership functions [24]. To determine the FOU boundaries of the set of type 2 fuzzy intervals, f_i^l the value of the input parameter is calculated by the standard deviation formula in the following equation;

$$f_i^l = exp\left[-\frac{1}{2}\left(\frac{x_i - c_{i1}^l}{\sigma_i^l}\right)^2\right], \sigma_i^l \in \left[\sigma_{i1}^l, \sigma_{i2}^l\right] \quad (7)$$

Then the membership function equation at $\bar{f}$ is addressed to equation (8);

$$\bar{f} = \begin{cases} c_{i1}^l, \sigma_i^l ; x_i \quad x_i < c_{i1}^l \\ 1, \ c_{i1}^l \le x_i \le c_{i2}^l \\ c_{i2}^l, \sigma_i^l ; x_i \quad x_i > c_{i2}^l \end{cases} \quad (8)$$

While the membership function for the type-2 fuzzy interval at $\underline{f}$ is shown in equation

$$\underline{f} = \begin{cases} \left(c_{i1}^l, \sigma_i^l ; x_i\right), x_i \le \frac{c_{i1}^l + c_{i2}^l}{2} \\ \left(c_{i2}^l, \sigma_i^l ; x_i\right), x_i > \frac{c_{i1}^l + c_{i2}^l}{2} \end{cases} \quad (9)$$

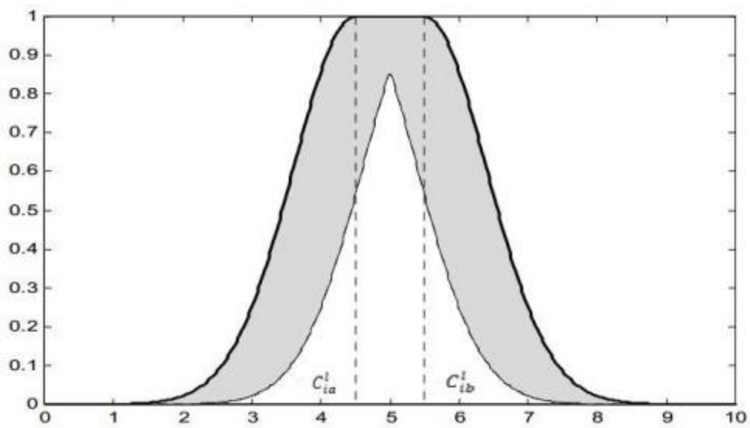


FIGURE 3. Consequent to Gaussian membership function

When the PSO becomes convergent, then the value of social factors will approach zero [25]. Meanwhile, changing the position of the particle best value to the agent's last position will create a value as shown below

$$p_i^k - x_i^k = 0 \quad (10)$$

The standard PSO equation can be seen in equation 11 below.

$$v_i^{n+1} = v_i^n + c_1 r_1 (pbest_i^n - x_i^n) + c_2 r_2 (gbest_i^n - x_i^n)$$

$$x_i^{n+1} = x_i^n + v_i^{n+1}$$

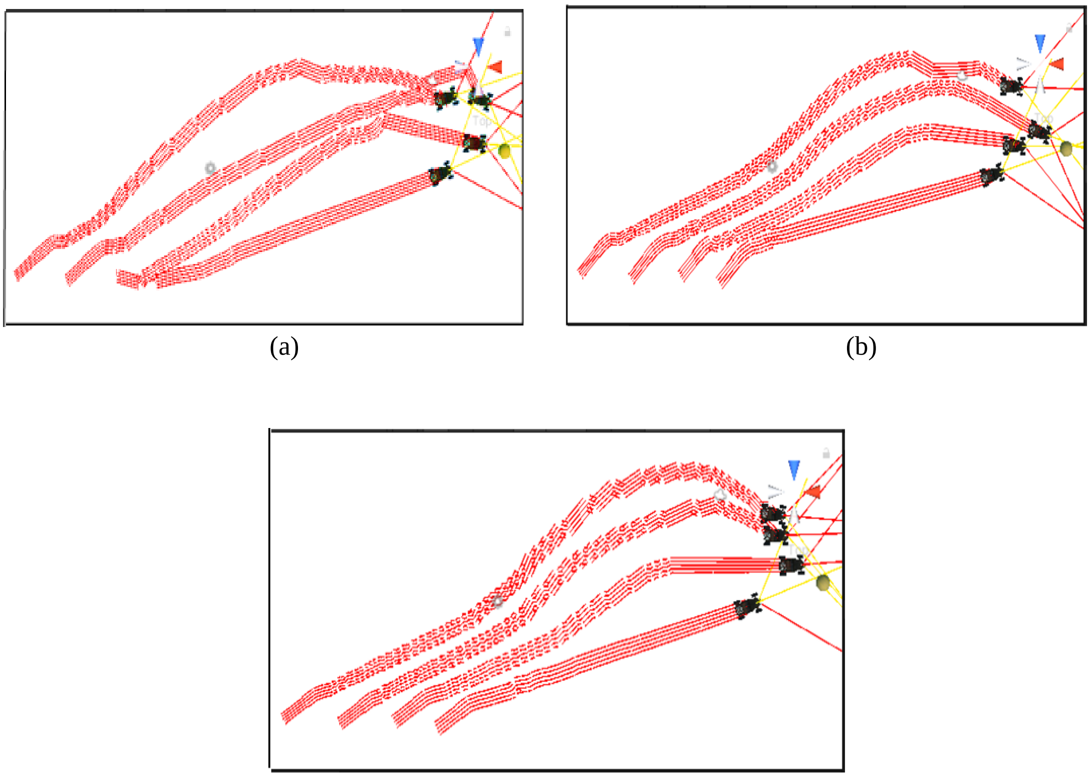
(11)

Based on equation 11, it can be simplified to:

$$\underbrace{v_i^{k+1} = v_i^k + c_1}_{\text{Individual}} * rand * (0) + \underbrace{c_2 * rand * (p_g^k}_{\text{Social}} - x_i^k) \quad (12)$$

3. RESULT AND DISCUSSION

In the first environmental test, there were no obstacles around the robot in reaching the target. After doing the first test, the trajectory results obtained from the movement of each multi-robot (robot 1, robot 2, robot 3, robot 4) which can be seen in the following figure:



(a) (b)

(c)

FIGURE 4. (a) Multi-Robot Movement in Reaching Target using Fuzzy Type 2 – PSO; (b) Multi-Robot Movement in Reaching Target using Fuzzy Type 2 – MPS; (c) Multi-Robot Movement in Reaching Target using Fuzzy Type 2 – DPSO

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From the trajectory in Figure 4 it shown that from the initial position the robot has moved by paying attention to the rotation angle and the walking speed of the robot to the target, which can be seen from the results of the trajectory that leads to one point. The following describes the initial position of each robot when it starts moving towards the target and the final position when the robot has reached the target and the time taken by each robot to reach the predetermined target.

TABLE 1.
The starting dan ending point coordinates with Time and angle taken by Robot in reaching the target using Fuzzy type 2 - PSO without any obstacles.

	Starting Point				End Point			
	Robot 1	*Robot 2*	*Robot 3*	*Robot 4*	*Robot 1*	*Robot 2*	*Robot 3*	*Robot 4*
X coordinates	-15,527	-11,447	-7,467	-4,397	21,474	19,468	20,755	18,337
Z coordinates	-6,922	-6,927	-6,957	-6,947	4,505	4,664	1,609	1,367
Time	7,342	7,337	7,323	7,311	62,64	62,63	62,63	62,62
Moving Speed	5,323	5,323	5,323	5,323	2,281	2,281	2,281	2,281

TABLE 2.
The starting dan ending point coordinates with Time and angle taken by Robot in reaching the target using Fuzzy type 2 - MPSO without any obstacles.

	Starting Point				End Point			
	Robot 1	*Robot 2*	*Robot 3*	*Robot 4*	*Robot 1*	*Robot 2*	*Robot 3*	*Robot 4*
X coordinates	-15,366	-11,286	-7,33	-4,266	21,277	19,43	20,249	17,763
Z coordinates	-6,965	-7,255	-7,125	-7,535	4,597	3,492	1,818	0,498
Time	5,33	5,327	5,317	5,307	19,61	19,61	19,60	19,59
Moving Speed	5,323	5,323	5,323	5,323	2,281	2,281	2,281	2,281

TABLE 3.
The starting dan ending point coordinates with Time and angle taken by Robot in reaching the target using Fuzzy type 2 - DPSO without any obstacles.

	Starting Point				End Point			
	Robot 1	*Robot 2*	*Robot 3*	*Robot 4*	*Robot 1*	*Robot 2*	*Robot 3*	*Robot 4*
X coordinates	-15,372	-11,292	-7,31	-4,24	22,702	18,921	19,844	18,334
Z coordinates	-6,969	-7,259	-6,982	-7,392	3,138	3,974	1,531	0,345
Time	8,347	8,337	8,307	8,279	26,13	26,126	26,12	26,11
Moving Speed	5,323	5,323	5,323	5,323	2,281	2,281	2,281	2,281

From Figures 5 (a), (b) and (c) it can be seen that robots can maintain a distance between one robot and another and Robot 1, robot 2, robot 3, robot 4 can reach the target. In Figures (a) and (c) it can be seen that the trajectory of the multi-robot movement is less smooth and the resulting time is longer than MPSO or it can be seen in comparisons in Tables 1, 2 and 3 that in table 1 the time taken by the robot at the starting point is approximately 7 seconds and the end point is approximately 62 seconds, then the time difference between the start point and end point of the robot's journey is approximately 55 seconds. In Table 2, the time taken by the robot at the starting point is approximately 5 seconds and the end point is approximately 19 seconds, so the time difference between the starting point and the end point of the robot's journey is approximately 14 seconds. In Table 3, the time taken by the robot at the starting point is approximately 8 seconds and the end point is approximately 26 seconds, so the time difference between the starting point and the end point of the robot's journey is approximately 18 seconds.

4. CONCLUSION

So it can be concluded that the time generated by using fuzzy logic type 2 - MPSO is smaller and the robot movement is smoother than fuzzy logic type 2 - PSO and fuzzy logic type 2 - DPSO. Then the speed controlled by the Fuzzy Logic Type 2 algorithm affects the change in speed with a difference that does not drastically change much so that the motion between robots can be controlled very well in avoiding collisions, although in this test it was not entirely successful or the motion between robots still collided.

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