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Jurnal Nasional Teknik Elektro

| ISSN (Print) 2302-2949 | ISSN (Online) 2407-7267 |

Navigation and Formation of Swarm Robotics with Local Positioning System

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ARTICLE INFORMATION

Received: May 20, 2022
Revised: October 17, 2022
Available online: November 30, 2022

KEYWORDS

Local Positioning System, Swarm Robotics, Bluetooth Low Energy, Navigation System

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A B S T R A C T

This paper discussed the method of navigation and robot formation in a swarm using the Local Positioning System (LPS) which was applied to the mobile robot's differential steering platform. Navigation and formation of robots in swarm robotics could run well because of the presence of robot position coordinates. In the outdoor application of coordinates, the position of the robot could be obtained easily using the Global Positioning System (GPS), but GPS had drawbacks in indoor applications. In indoor use, signals from satellites were difficult to obtain and inaccurate for use with relatively short distances. In coordinate research, positioning used LPS which was built using Bluetooth Low Energy (BLE). LPS with BLE was successfully built with simple resources and at a low price but had optimal performance. The LPS accuracy built with BLE and the regression algorithm had an error of 4.33% on the X-axis, and 2.67% on the Y-axis. The robot formation utilized a combination of proximity sensors and position coordinates obtained from LPS. The proximity sensor served to detect obstacles that hold the robot towards a predetermined target. The combination of navigation algorithms and swarm formation robotics was proven to be faster at finding targets compared to a single robot.

INTRODUCTION

The development of robot technology currently is so fast. Robots that used to work individually are now starting to shift to cooperation between robots. This development starts from communication between robots to complete work and submit the results of their work to other robots according to their specialization, to work in groups (swarm robotics). The swarm robotics inspired from nature is a combination of swarm intelligence and robotics [1]. Swarm robotics is very suitable to be applied to the completion of complex and dangerous work, such as finding the location of gas leakings, searching for disaster victims, and various other applications that are difficult for humans to perform. As an example of the application of swarm robotics that is very possible to do is odor plume tracking [2]. Searching for odor plumes with a single robot encounters problems if there is a change in wind direction [3] [4], as in Fig. 1. It is possible that the swarm robotics search will be more robust than the single robot search method, as shown in Fig.2.

In tracing using swarm robotics, it is not easy to lose track of the odor plume when the wind direction changes, Fig. 2(b). This is because it is still possible that there are other robots in the formation in the odor plume distribution area so that they can provide information on the presence of the odor plume to other robots.

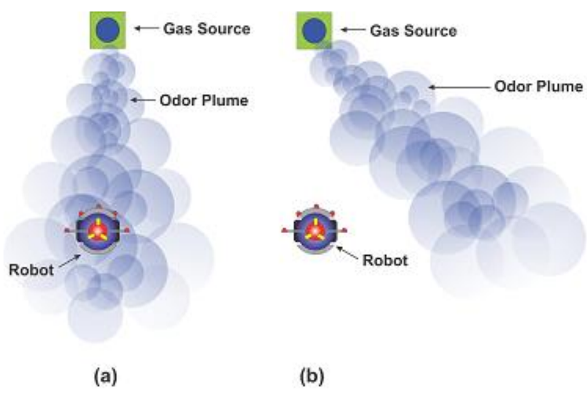

Figure 1. Odor plume search with a single robot. (a) When there is no change in wind direction (b) When there is a change in wind direction.

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Swarm robotics has advantages in completing a mission compared to a single robot which is very sophisticated and supported by very complete equipment. In swarm robotics, if one of the robots has problems, there are still other robots that will continue the mission [5]. The individuals can be regarded as agents with simple and single abilities. Some of them have the ability to evolve themselves when dealing with certain problems to make better compatibility [6 - 8].

Key to success of swarm robotics lies in the navigation and formation of the robot. In this case knowing the position of the robot is very important. The position of the robot for outdoor implementation can use the Global Positioning System (GPS) [9], but it becomes an obstacle if its implementation is indoor. In indoor implementation, it is often difficult to get signals from satellites. Besides, position accuracy for very close distances can not be obtained. The use of a Local Positioning System (LPS) for indoor implementation is absolutely necessary in swarm robotics. Therefore this study emphasizes on the method of navigation and formation of robots in a swarm using LPS.

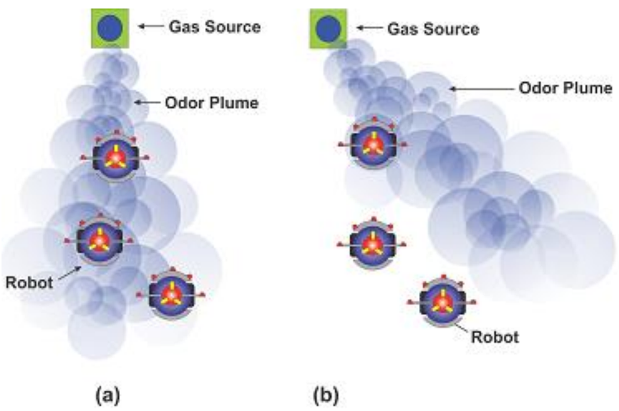

Figure 2. Odor plume search with multi agent (a) When there is no change in wind direction (b) When there is a change in wind direction.

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METHOD

In swarm robots, each individual robot is equipped with communication equipment that is useful for communication between robots, a Local Positioning System (LPS) to determine the coordinates of the robot's position, an algorithm to regulate the formation of a mobile robot, and a navigation algorithm to regulate the robot's navigation to a predetermined target. The robot navigation algorithm also functions to ensure that all robots in formation move a predetermined distance, adjust speed to avoid collisions between robots, avoid obstacles, and move to follow the leader. The diagram of the swarm robots formation arrangement and navigation system can be seen in Fig. 3.

This study uses a differential steering mobile robot platform [15] [16] equipped with a Local Positioning System (LPS) and a distance sensor which functions to determine the coordinates of the robot's position and avoid obstacles. The specification of the robot used is a wheel diameter of 10 cm, and a speed range of 471 cm/s to 2500 cm/s. The robot platform used in this study can be seen in Fig. 4

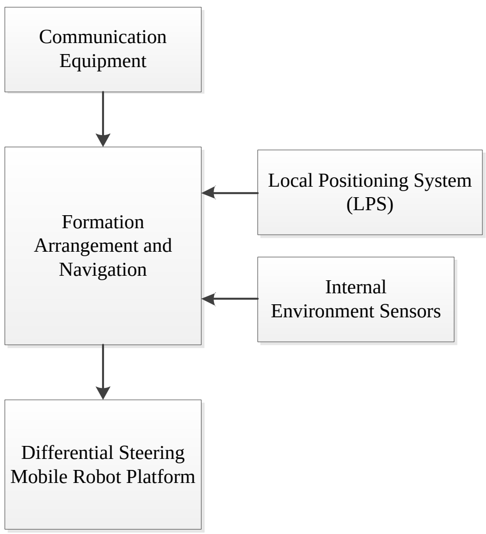

Figure 1. Swarm Robots Formation Arrangement and Navigation

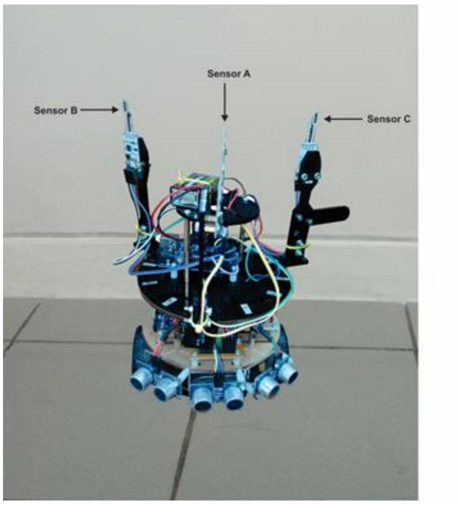

Figure 4. Mobile Robot Platform

Robot Formation

In this section, a controller algorithm method is designed for a group of mobile robots that follow each other between other robots, where the robot will run according to the movement of the robot leader [17]. The purpose of this control method is to create a robot colony that can move from side to side with a predetermined distance, speed and orientation angle and adjusted to the robot leader. The nonholonomic model for each robot is:

$$x = v\cos\emptyset \\ y = v\sin\emptyset \\ \emptyset = \omega \quad (1)$$

Where v, θ dan ω denote the speed, rotation and angular velocity of the robot in a fixed coordinate system. The XL and YL axes are as Figure 5. The center point is denoted on a line that has an angle β0 from the robot's orientation axis, and has a distance L from the robot's center point. if the robot has a center point x and y then it can be written as the following equation.

$$X_L = x + L\cos(\emptyset + \beta 0) \quad (2)$$
$$Y_L = y + L\sin(\emptyset + \beta 0) \quad (3)$$

From the equation (1), (2), and (3) it is found that the relationship between the speed and angular velocity of the robot (v,ω) to the movement at the coordinates of the X_L and Y_L points, so it can be written as follows.

$$\begin{bmatrix} X_L \\ Y_L \end{bmatrix} = \begin{bmatrix} \cos\emptyset - L\sin(\emptyset + \beta 0) \\ \sin\emptyset - L\cos(\emptyset + \beta 0) \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix} \quad (4)$$

The formation and distance between the robots or the desired separation in achieving the target coordinates is shown in Figure 6.

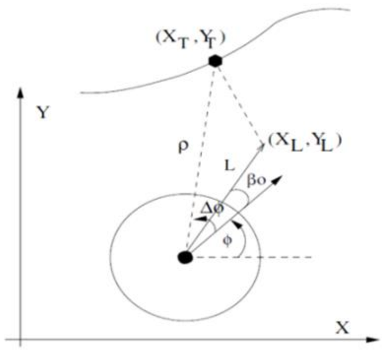

Figure 5. Robot Movement

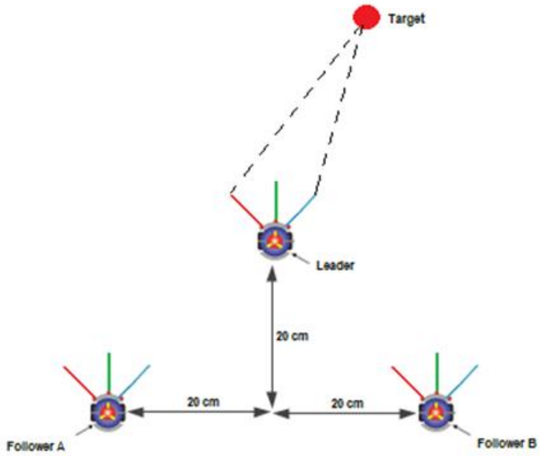

Figure 6. Robot Formation

Local Positioning System

Local Positioning System (LPS) is useful for knowing the coordinates of the robot's position. The position coordinates are needed by the robot to adjust the distance between the robots, and the formation settings to find the target. The method used to determine the coordinates of the robot's position in this study is Trilateration Estimation.

Trilateration estimation is a method for determining location based on signal strength measurements from three transmitters around an object [18][19]. This study uses three Bluetooth Low Energy (BLE) [20]. By utilizing the Receive Signal Strength Indicator (RSSI) from BLE, we can find out how far the distance between the transmitter and receiver is [21]. For more details, see Figure 7. If Pr(d0) is the transmit power of the transmitter received by the receiver within 1 meter with units of dBm, d is the distance between transmitter and receiver, and n is the order of attenuation, then the relationship between distance and RSSI [22-26] can be written as follows.

$$RSSI[dBm] = P_{r(d0)} - 10 \times n \times Log_{10}\left(\frac{d}{d0}\right) \quad (5)$$

$$d(cm) = 10^{\frac{(P_{r(d0)} - RSSI)}{10n}} \quad (6)$$

The order of attenuation for free space conditions without obstructions is n = 2, while in different environmental conditions, the magnitude of the damping order can be calculated bythe equation.

https://doi.org/10.25077/jnte.v11n3.1023.2022

$$n = \frac{(P_{r(d0)} - P_{r(d)})}{10 \times \log_{10}(d/d_0)} \quad (7)$$

The position of the robot coordinates (x,y)) can be determined by measuring the distance (d) of the robot from the three BLE, which is named anchor R. To get the value (x), we can calculate it using anchors R1 dan R2 as reference nodes, as well as the value (y), we can use anchors R1 dan R3 as reference nodes. (x) and (y) can be expressed as follows:

$$x = \frac{u^2 + (d_1^2 - d_2^2)}{2u} \quad (8)$$

$$y = \frac{v^2 + (d_1^2 - d_3^2)}{2v} \quad (9)$$

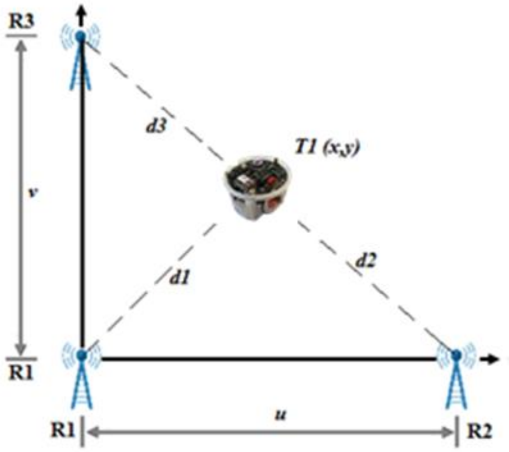

Figure 7. Trilateration Estimation

RESULTS AND DISCUSSION

LPS

This study uses three anchors as radio transmitters as shown in Figure 8. To find out the distance between the robot and the anchor, it can be done by measuring the RSSI of the anchor received by the robot. The amount of RSSI received by the robot based on distance can be seen in Figure 9. The regression formula to determine the distance from the RSSI received by the robot is as follows:

$$y = -389.051 + -8.46502\ x \quad (10)$$

From the results of the RSSI test, it can be seen that there is almost no difference between the test data and the sampling data, making it possible to build LPS with BLE. The results of the position coordinate test can be seen in Figure 10.

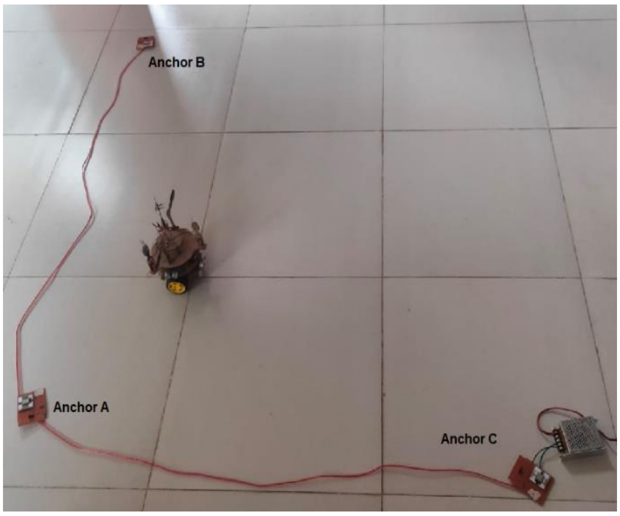

Figure 8. Anchor Placement

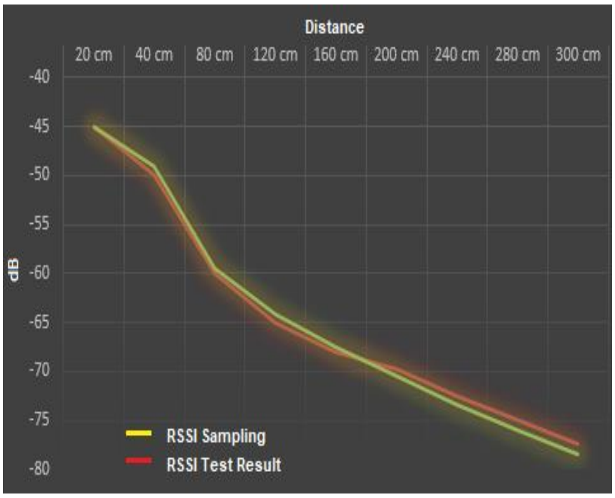

Figure 9. RSSI Test Results Based On Distance

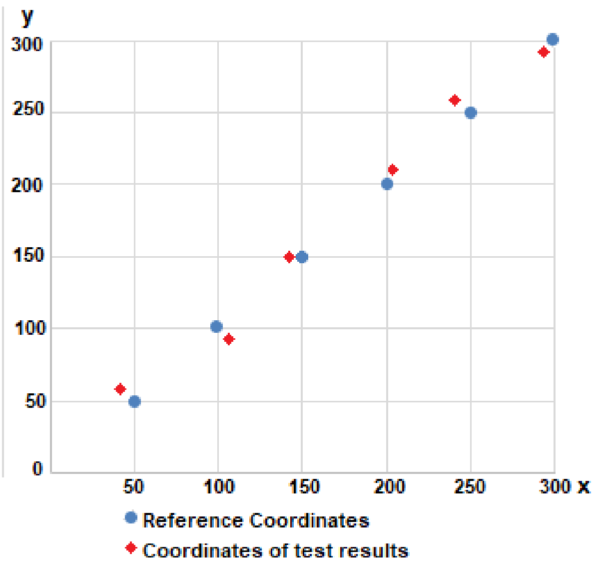

Figure 10. Position Coordinate Test Results

The error value of the reference coordinate reading results compared to the test results can be seen in table 1.

Table 1. Position Coordinate Test

No	Reference Coordinates		Coordinates of Test Result		Error	
	x	y	x’	y’	x	y
1	50	50	45	54	5	-4
2	100	100	105	94	-5	5
3	150	150	148	150	2	0
4	200	200	202	203	-2	-3
5	250	250	240	252	10	-2
6	300	300	298	298	2	2
			Average error		4.43	2.67

Robot Navigation

The results of testing the movement of the follower robot when following the target coordinates that have been sent by the leader robot to the target coordinates, when there are no obstacles can be seen in Figure 11, while the follower robot's response to the target coordinates when passing an obstacle is shown in Figure 12.

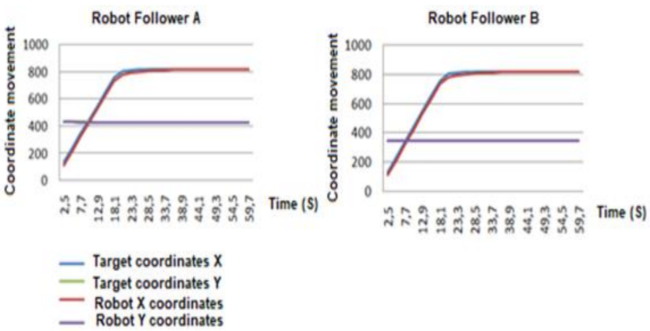

Figure 11. The Response of The Follower Robot's Movement When It Goes to The Target Coordinates Without Any Obstacles.

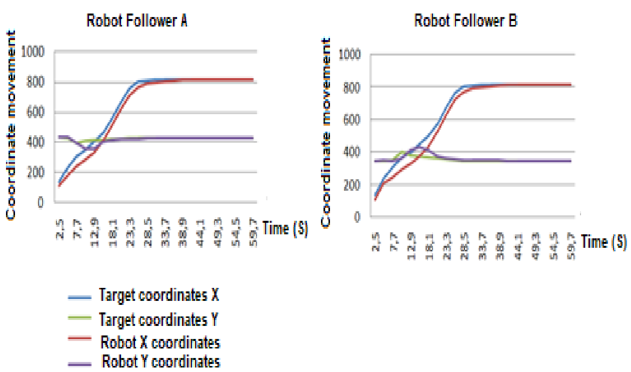

Figure 12. The Response of The Follower Robot's Movement When It Goes To The Target Coordinates Through Obstacles.

CONCLUSIONS

The LPS built in this study has an average error of 4.33% on the X axis, and 2.67% on the Y axis. Thee establishment of formation after passing through the obstacle can be done based on the delivery of the destination coordinates by the main robot. Speed coordination is carried out based on the distance and coordinates of each robot to other robots.

ACKNOWLEDGMENT

All academicians of Institut Teknologi Telkom Surabaya. This research was funded by Telkom Institute of Technology Surabaya.

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