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A Multi-robot System Coordination Design and Analysis on Wall Follower Robot Group

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ABSTRACT

In this research, multi-robot formation can be established according to the environment or workspace. Group of robots will move sequently if there is no space for robots to stand side by side. Leader robot will be on the front of all robots and follow the right wall. On the other hand, robots will move side by side if there is a large space between them. Leader robot will be tracked the wall on its right side and follow on it while every follower moves side by side. The leader robot have to broadcast the information to all robots in the group in radius 9 meters. Nevertheless, every robot should be received information from leader robot to define their movements in the area. The error provided by fuzzy output process which is caused by read data from ultrasound sensor will drive to more time process. More sampling can reduce the error but it will drive more execution time. Furthermore, coordination time will need longer time and delay. Formation will not be establisehed if packet error happened in the communication process because robot will execute wrong command.

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1. INTRODUCTION

Mostly, research in robot applications is focused on human work assistance wether it's controlled manually or move autonomously. To support that jobs, there are so many complex problems need to be solved, such as control mechanism, AI and decision making system, path planning and mobile navigation system. However, most of them are focused on single robot behaviour only. So, in our current research we tried to apply design and analyze problem in multi-robot. Currently, we focus on how robot communicate each other in order to share retrieved sensor data to make a coordinated movement. In the wider aspects, robots can move in uniform movement and accomplish task more efficient.

Multi-robot coordination is purposed to make robots can share any information between them. For example, a robot position can be shared to others in order to define more precise other robot position and avoid collision. In the other hand, a robot can find efficient route or path different from each other. So, it can widen operational area of robots environment. Besides, it can be used in robot applications which need formation, as example in robot soccer team.

Robot ability usually has limitation depends on its program. In some cases, a group of robots can finish task faster than a single robot. Moreover, by using multi-robot, it will widen the working area wether for searching, monitoring, or other jobs. Despite to apply the multi-robot system, there are many aspects which have to be considered. Main problem from those is how to design and implement an intelligent system which can define simultanous path by communication and coordination system based on each robot information. Furthermore, a group of autonomous robots has to avoid collision from each other by defining each path based on shared data [1]. It is different to some others research which only applied a single robot, especially in defining a path. For example, in Tatiya Padang Tunggal *et al.* they only applied fuzzy cell-decomposition to define a path in a single robot [2].

Multi-robot system must be designed to have ability in collecting and integrating data from robots wether it's uniform or not [3]. We can explore from ants which live in colony. They have a kind of system when they travel, an ant will leave ammonia to ease other ants follow the path [4]. Based on that movement, ant colony mostly similar to leader-follower mechanism in multi-robot. It's important of a group robot to have a leader to ease tha data acquisition system and solve the jobs [5].

Research in Multi-Robot, mostly develops control system based on computer process [6]. Besides, there are some kind of multi-robot autonomous control system, which robot will ove autonomos after activated without any other commands [7]. Moreover,distributed control system is one of popular research area related to multi-robot controlling. One of them was focused on collision avoidance between robots when trying to accomplish the given mission [8]. In advance, robot can avoid collision without stopping their movement [9].

On the other hand, there were multi-robot agorithm evaluated to assemble robots in a similar location [10], [11]. It can evaluate leader-follower algorithm context and also one kind of test to define the reability of the mechanism. Another mechanism of that, follower robot will move by following the leader track [12]. Then, it were developed by applying distribution control and information sharing so that follower robot can move more precisely to adjust the speed, path, and orientation [13].

Network connectivity is also one of important part in multi-robot. It should be reliable in multi-robot to avoid information missundertanding between robots because robots will always communicate during operation.There were two kind of communication, decentralized and centralized method. In decentralize or distributed method, connectivity can handlelarge amount of robots [14]. While in centralized method, it has to be define a robot as a leader which will handle data from all of robots. In network, it also similar as a router. Every single robot will move based on data come from leader [15], [16]. It is effective and efficient for small amount of robots.

In this research, we will apply a small group of robots consist of four which one robot will be defined as a leader. It will be an evaluation to determine the reability of multi-robot mechanism which mainly purposed to maintain the formation of robots with simplest possible algorithm. It means that the computation expected is as mild as possible. In our previous research, it is proved that designed algorithm can run properly in arduino based controller where follower robot can move through leader track [17]. We applied less complexity than either swarm system or localization methods presented in [18] and [19] in order to make a quick respond system in only a simple robots.

In this paper, it will be presented the designed mechanism of communication and how the robots make a proper coordination between them. This paper will be arranged as follows: in section 1, it is already presented an introduction of the research and related works of that; while the system and method will be put on the section 2; in section 3, testing scenarios, results, and evaluation of the system are given; as a last section, in section 4 will be presented a conclusion and the description of our future works related to current publication.

2. SYSTEM DESIGN

Generally, system consists of four uniform robots which can communicate each other for coordination. Each robot has embedded processor as main controller, two dc-motors for actuator, and sensor system for localization input in defining position such as ultrasound and compass sensor. Besides, for communication each of them has an RF based tranceiver-receiver which works on frequency channel 433 MHz. From them, a robot has a role as leader while others will be follower. Each Robot Hardware Block System as shown in Figure 1.

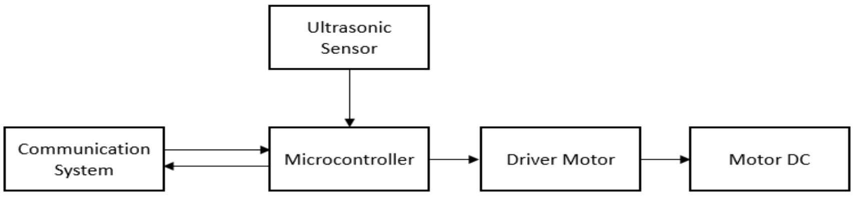

Figure 1. Each robot hardware block system

Ultrasound sensors are needed to defined the position on a maze base on range between robot and front-side walls. While compass sensor will determine the robot orientation. Besides, ultrasond can help robot to move arround and avoid collision wether with or without data from other robot. After each robot defines its position and orientation, they will send that information to leader robot in order to be processed. Leader robot will compare every received information with its own to determine the next step for each robot movement. The communication scheme used in this research was a broadcast or mesh network so that every robot can communicate directly to others even the decision will be made by leader only. It helped widening the range because it was defined that every follower robot will always resend data come from other follower till it received by leader. Used Communication Network Scheme of Multi-Robot as shown in Figure 2.

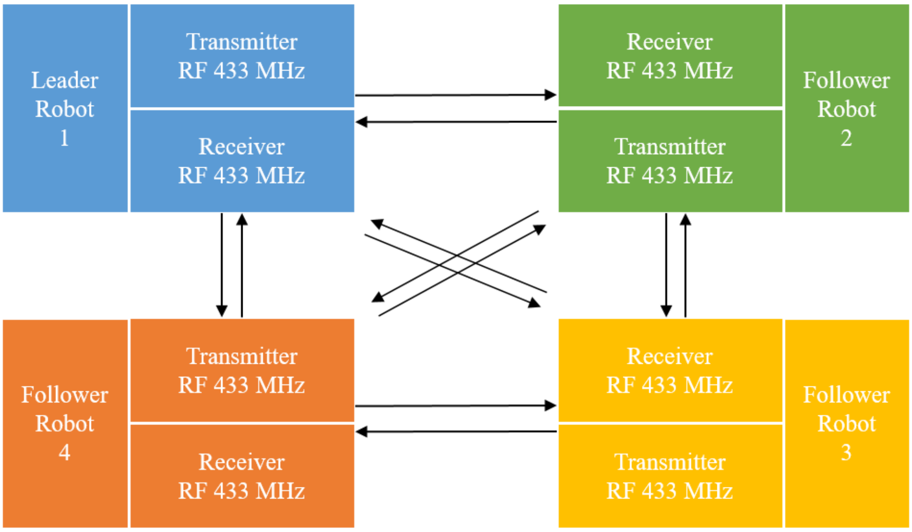

Figure 2. Used Communication Network Scheme of Multi-Robot

For communication and navigation sharing necessity, there were created come precedure and data format to be sent by robots to group. Since there are two kind of formations desired, procedure created also have differences between them.

2.1. Paralel Robot Formation

In paralel formation, follower robots will move forward by following leader's track behind. Paralel formation is equal to sequential formation where robots move in a straight line. This formation is very useful when robots find a narrow lane. There were some procedures to define the paralel formation as follows:

1. At first, robot move by using wall following algorithm which following a right wall based on efined range (3cm from the wall).
2. If leader robot find an obstacle in front of it, it will send EIM data to others. Then, it will turn left and move forward until data B is received.
3. Follower robot at the second position will stop when it receive an EIM data for a moment (delay set), and move again by wall following on the right wall.
4. The second robot will send IM data to robots behind it when find an obstacle in the front (obstacle can be a leader also) and make a turn to left the follow the right wall.
5. If the third robot find an obstacle, others will be stopped. It will send data AEM to fourth robot. Other behaviour is equal to leader n second robot.
6. For the last robot, it will send AEI data if it find an obstacle and the make a left turn and send BFJ data to all robots. The next procedures are back to the first.

To determine movement steps of multi-robot above, data format which known by each robot have to be designed. To ease the procedures, data format created as simple as possible so that it only uses a string or character to define commands. However, commands are defined by sensor input condition based on environment. As described before, sensor used consist of ultrasound to define an obstacle and range to the wall, and compass use to find robot orientation. On the Table 1, shown messages creted to be sent from one to other robots.

Table 1. Communication and Navigation Procedure of Multi-Robot Paralel Formation

ROBOT 1		ROBOT 2		ROBOT 3		ROBOT 4	
MOVEMENT	DATA	MOVEMENT	DATA	MOVEMENT	DATA	MOVEMENT	DATA
RWF		RWF		RWF		RWF	
AP4 FUZZY							
STOP							
SEND	EIM	RECEIVE	EIM	RECEIVE	EIM	RECEIVE	EIM
TURN LEFT		STOP		STOP		STOP	
		DELAY		DELAY		DELAY	
FORWARD		RWF		RWF		RWF	
STOP		AP4 FUZZY					
ROBOT 1 STOP UNTIL		STOP					
RECEIVE DATA ‘B’		SEND	IM	RECEIVE	IM	RECEIVE	IM
		TURN LEFT		STOP		STOP	
				DELAY		DELAY	
		FORWARD		RWF		RWF	
RECEIVE	B	SEND	B	AP4 FUZZY			
RWF		RWF		STOP			
RECEIVE	AEM	RECEIVE	AEM	SEND	AEM	RECEIVE	AEM
STOP		STOP		TURN LEFT		STOP	
ROBOT 1 DAN 2 STOP UNTIL RECEIVE DATA ‘BF’						DELAY	
				FORWARD		RWF	
RECEIVE	BF	RECEIVE	BF	SEND	BF	AP4 FUZZY	
RWF		RWF		RWF		STOP	
RECEIVE	AEI	RECEIVE	AEI	RECEIVE	AEI	SEND	AEI
STOP		STOP		STOP		TURN LEFT	
ROBOT 1, 2, DAN 3 STOP HINGGA MENERIMA DATA ‘BFJ’						FORWARD	
RECEIVE	BFJ	RECEIVE	BFJ	RECEIVE	BFJ	SEND	BFJ
RWF		RWF		RWF		RWF	

2.2. Serial Robot Formation

When robots detect and define larger area which is fit to put robots together in a row, then Multi-Robot system will be entered the serial formation mode. In this mode, robots will move forward together in a same row and in equal speed. The difficult problem is when robots find obstacle or wall in front of them, so that they have to make a turn. But, it will be defined by the leader where the postion is nearest to the right wall. Procedures is determined as follows:

1. When leader robot detects an obstacle or wall on the front, it will stop move at a moment and check the left side. If the distance is more than 10cm to the second robot, it will send the GIM data to command the second robot to stop. Besides, it will also send EKM data to stop the other follower robot.
2. Soon after the second robot stops, it will also check the left side and repeat the procedure used by leader robot. Stop command is defined as IO data.
3. Meanwhile, robot 3 will also check its left side and send M data to robot 4.

Data flow from procedure above also can be shown by table 2 below. Meanwhile, Figure 3 shows the flow process and communication between leader and follower robots.

Table 2. Communication and Navigation Procedure of Multi-Robot Serial Formation

ROBOT 1		ROBOT 2		ROBOT 3		ROBOT 4	
MOVEMENT	DATA	GERKAN	DATA	MOVEMENT	DATA	MOVEMENT	DATA
RWF		RWF		RWF		RWF	
AP4 FUZZY							
STOP							
SEND	GIM	RECEIVE	GIM	RECEIVE	GIM	RECEIVE	GIM
STOP		RWF		STOP		STOP	
LEFT SENSOR							
CHECK < 10 ?							
SEND	EKM	RECEIVE	EKM	RECEIVE	EKM	RECEIVE	EKM
STOP		STOP		RWF		STOP	
		CEK SENSOR					
		KIRI < 10 ?					
		SEND	IO	RECEIVE	IO	RECEIVE	IO
		STOP		STOP		RWF	
				CEK SENSOR			
				KIRI < 10 ?			
				SEND	M	RECEIVE	M
				STOP		STOP	

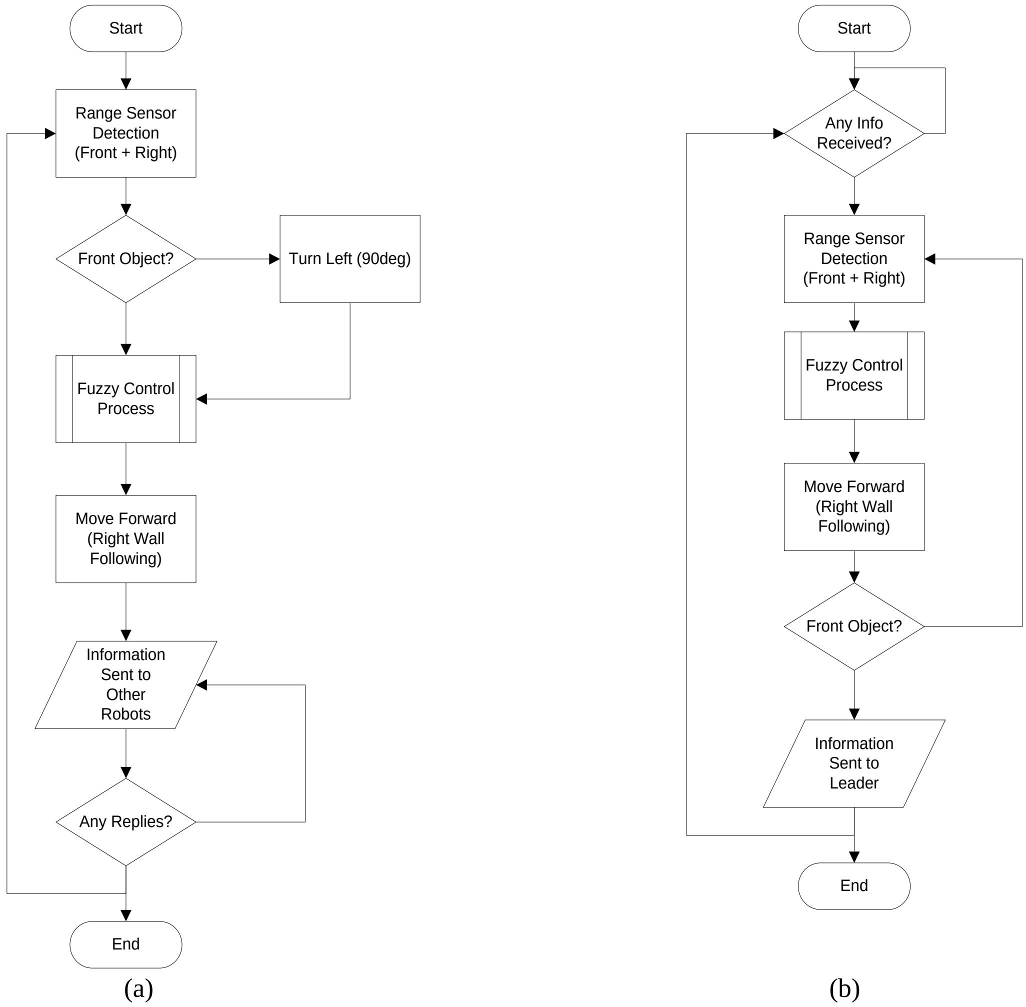

Figure 3. Flow Chart of Formation Scheme (a) Leader Robot, (b) Follower Robot

2.3. Movement Robot Control

Generally, robot moves by grabbing on the right wall or commonly known as right wall following method. It is a kind of simplest method to move and commonly used by blind mobile robot which only depend on range sensor. To define the decision to move, fuzzy logic scheme is designed using two input by using range sensor. It can be shown on the Figure 4 below.

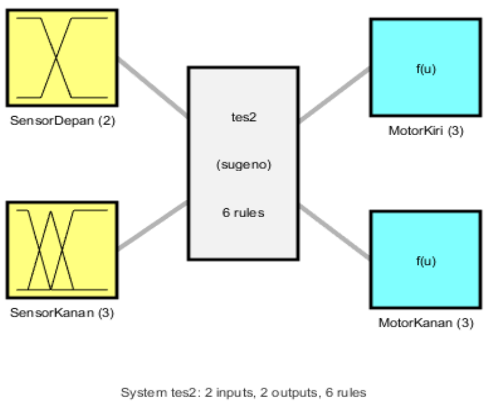

Figure 4. Fuzzy Logic Design (16)

$$F_{far}(x) = \begin{cases} 1 & ,x \geq 18 \\ \frac{x-8}{18-8} & ,8 < x < 18 \\ 0 & ,x \leq 8 \end{cases} \quad (1)$$

$$F_{near}(x) = \begin{cases} 1 & ,x \leq 8 \\ \frac{18-x}{18-8} & ,8 < x < 18 \\ 0 & ,x \geq 18 \end{cases} \quad (2)$$

Formulations above is defined for front sensor. It is used to make a decision to move or stop. On the other hand, the right sensor is used for defining the speed of motors and make a robot moving by grabbing the right wall. Furthermore, in the follower robot, it can be used for detecting the other robot on their right side. All values are defined as a range in centimeters.

$$R_{far}(x) = \begin{cases} 1 & ,x \geq 40 \\ \frac{x-15}{25-15} & ,20 < x < 40 \\ 0 & ,x \leq 20 \end{cases} \quad (3)$$

$$R_{mid}(x) = \begin{cases} 1 & ,x = 15 \\ \frac{x-5}{15-5} & ,5 < x < 15 \\ \frac{25-x}{25-15} & ,15 < x < 25 \\ 0 & ,5 \geq x \geq 25 \end{cases} \quad (4)$$

$$R_{near}(x) = \begin{cases} 1 & ,x \leq 5 \\ \frac{15-x}{15-5} & ,5 < x < 15 \\ 0 & ,x > 15 \end{cases} \quad (5)$$

Figure 5 above shows the defuzzyfication result of the process. It gives the motor speed between right and left in order to make a robot move forward by following the right wall. In the result, it still produces the oscillation which is cused by different dc motors problem. Defuzzyfication process is based on the following formula.

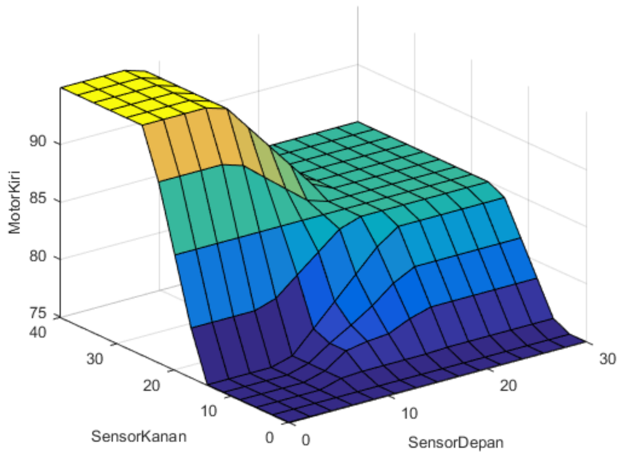

Figure 5. Fuzzy Logic Output Surface based on Two Sensor Inputs

$$y^* = \Sigma \frac{\mu(y) \times y}{\mu(y)} \quad (6)$$

3. RESULTS AND ANALYSIS

It is important to test the designed system in order to know how reliable it is. Moreover, it can be used to verify the system performance. Ther are some parameters used to measure the performance of the system.

First of all, we have test how the communication can cover coordination between robots. Delay parameter was used to know how good the used communication system is. Results of the measurement can be seen below. For information, data was sent all from leader robot. Based on the result shown in Table 3, delay can be minimized by using transfer rate 4000bps on the communication system. However, distance between robot also affects the delay. Maximum distance of data transfer is 9 meters for this kind of transceiver. On the other hand, if we applied 2000bps of transfer rate, data transfer process is produce more stability and the variance of delays is less. At some point, it can be used more than 9 meters. Received signal strength is still in the range to be accepted by receiver. Regarding to the evaluation of communication system, we make a boundary of the robots workspace in a 9 meters radius. It is used because the leader robot have to broadcast the information to all robots in the group. Nevertheless, every robot should be received information from leader robot to define their movements in the area.

Then, it has been tested how robots execute their command from leader robot. It is shown on the Table 4, that every robot in the group mostly executes command accurately based on received data. It can be concluded that all of command from leader can be received by follower robots without error, so that follower robots can execute them accurately. Multi-robot formation can be established according to the environment or workspace. Group of robots will move sequently if there is no space for robots to stand side by side. Leader robot will be on the front of all robots and follow the right wall. On the other hand, robots will move side by side if there is a large space between them. Leader robot will be tracked the wall on its right side and follow on it while every follower moves side by side.

Table 3. Delay Testing Result

No. Sampling	Rate	Transmitter	Robot 1		Robot 2		Robot 3	
		Sent data	Received data	Delay (s)	Received data	Delay (s)	Received data	Delay (s)
1	4000 bps	ABC	ABC	0.15	ABC	0.15	ABC	0.15
2	4000 bps	ABC	ABC	0.13	ABC	0.13	ABC	0.13
6	4000 bps	AB	AB	0.13	AB	0.13	AB	0.13
7	4000 bps	AB	AB	0.14	AB	0.14	AB	0.14
11	4000 bps	A	A	0.12	A	0.12	A	0.12
12	4000 bps	A	A	0.13	A	0.13	A	0.13
16	2000 bps	ABC	ABC	0.19	ABC	0.19	ABC	0.19
17	2000 bps	ABC	ABC	0.16	ABC	0.16	ABC	0.16
21	2000 bps	AB	AB	0.2	AB	0.23	AB	0.23
22	2000 bps	AB	AB	0.22	AB	0.22	AB	0.22
26	2000 bps	A	A	0.22	A	0.22	A	0.22
27	2000 bps	A	A	0.17	A	0.17	A	0.17
31	1000 bps	ABC	ABC	0.7	ABC	0.49	ABC	0.49
32	1000 bps	ABC	Failed	Packet Loss	Failed	Packet Loss	Failed	Packet Loss
38	1000 bps	AB	Failed	Packet Loss	Failed	Packet Loss	Failed	Packet Loss
39	1000 bps	AB	Failed	Packet Loss	Failed	Packet Loss	Failed	Packet Loss
41	1000 bps	A	A	0.2	A	0.2	A	0.2
42	1000 bps	A	A	0.2	A	0.2	A	0.2

Table 4. Robot Execution Test

Testing Number -	Robot Leader		Robot Follower			Annotation
	Send Data	Sent Data	Receive Data	Received Data	Move as sent command	
1	Yes	Yes	Yes	Yes	Yes	Accurately
2	Yes	Yes	Yes	Yes	Yes	Accurately
3	Yes	Yes	Yes	Yes	Yes	Accurately
4	Yes	Yes	Yes	Yes	Yes	Accurately
5	Yes	Yes	Yes	Yes	Yes	Accurately
6	Yes	Yes	Yes	Yes	Yes	Accurately
7	Yes	Yes	Yes	Yes	Yes	Accurately
8	Yes	Yes	Yes	Yes	Yes	Accurately
9	Yes	Yes	Yes	Yes	Yes	Accurately
10	Yes	Yes	Yes	Yes	Yes	Accurately

4. CONCLUSION

On the multi-robot cases, every robot in the group can communicate in order to share information between them simultanoeously. It is purposed to make a good coordination for environtment exploration or in a simplified case, navigation. In the bigger purpose, a group of robots can explore and mapped the unknown environtment quicker than single mobile robot.

In our case, multi-robot formation can be established according to the environment or workspace. Group of robots will move sequently if there is no space for robots to stand side by side. Leader robot will be on the front of all robots and follow the right wall. On the other hand, robots will move side by side if there is a large space between them. Leader robot will be tracked the wall on its right side and follow on it while every follower moves side by side.

Based on performance testing, formation can be established accurately without error on communication. The error is provided by fuzzy output process which is caused by read data from ultrasound sensor. More sampling can reduce the error but it will drive more execution time. Furthermore, coordination time will need longer time and delay.

Communication process between leader and follower robot used RF 433MHz tranceiver module with rate 4000bps in order to minimize transmission delay. Based on test, there was no packet loss until the maximum distance 9 meters. Packet loss or error transmission would make robot execute wrong command so that the formation could not be established.

In the near future, we plan to develop more process in the multi-robot schemes such as collision avoidance and task allocation. It will be purposed to gain less time process in target or destination accomplishment. For the example, that four robots will determine their task independently based on information shared and their position in the maze, and define each path to reach the target differently.

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