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Two Algorithms For Static Polygon Shape Formation Control

Bayadir A. Issa*, Abdulmuttalib T. Rashid
Electrical Engineering Department, University of Basrah, Basrah, Iraq

Correspondence
*Bayadir A. Issa
Electrical Engineering Department,
University of Basrah, Basrah, Iraq
Email: bayader.phd@gmail.com

Abstract
This paper provides a two algorithms for designing robust formation control of multiple robots called Leader- Neighbor algorithm and Neighbor-Leader algorithm in unknown environment. The main function of the robot group is to use the RP lidar sensor attached to each robot to form a static geometric polygon. The algorithms consist of two phases implemented to investigate the formation of polygon shape. In the leading- neighbor algorithm, the first stage is the leader alignment and the adjacent alignment is the second stage. The first step uses the information gathered by the main RP Lidar sensor to determine and compute the direction of each adjacent robot. The adjacent RP Lidar sensors are used to align the adjacent robots of the leader by transferring these adjacent robots to the leader. By performing this stage, the neighboring robots will be far from the leader. The second stage uses the information gathered by adjacent RP sensors to reposition the robots so that the distance between them is equal. On the other hand, in the neighbor-leader algorithm, the adjacent robots are rearranged in a regular distribution by moving in a circular path around the leader, with equal angles between each of the two neighbor robots. A new distribution will be generated in this paper by using one leader and four adjacent robots to approve the suggested leader neighbor algorithm and neighbor-leader algorithm .

KEYWORDS: Mobile robot, RP lidar sensor, polygon shape formation, leader- neighbor.

I INTRODUCTION

Mobile robots formation control has many applications such as transportation, observation and search tasks. Therefore, it has been considered by many researchers [1-5]. Formation control means the problem of maintaining the relative position and orientation of robots in a cluster while at the same time enabling the cluster to travel in general. The utilization of formation control allows one to accomplish complex missions as every specific task can be achieved in one robot navigation [6,7]. Fundamental formation control issue includes maintaining required geometric movements of adjusting shapes and sizes such as triangular, square, polygon or section. Numerous types of control methods have been proposed to control the formation such as support issues [8, 9] including a virtual-structure approach, behavior-based approaches, and Leader-follower approaches [10]. Behavior based approach is decentralized control method used to control one or more robots in a group; note that the decentralized control method means there is no planning or reasoning to generate the responses [11-13]. Means there is no central part mange the system. So, its implemented with less communication, behavior based approach make the robots drive the controls for multiple computing objects at the same time. Also, in behavior based approach several states are prescribed for each robot and the final control is derived from a weighting of relative importance of each state [14-16]. In virtual structure approach the entire formation is regarded as a single structure where each robot is given a set of control to follow the desired trajectory of formation as rigid body. The main advantages of this approach is that a single mathematical rule translate the entire sensory input space into the actuator output space without the need of multiple rules or behaviors [17]. While the leader-follower methodology is that one robot goes about as a leader whose movement characterizes the way for the whole gathering. All follower robots will utilize the characterized way to accomplish a specific objective or to accomplish a characterized task. Follower robots should situate themselves as per the position and direction of the leader[18]. By and large, a few sorts of methodologies are presented in the writing for keeping up formation dependent on the leader-follower approach. The followers ought to keep up an ideal relative posture concerning the facilitate outline fixed on the leader and now and again, it is essential for every robots to pursue more than single guided robot to accomplish a particular formation along these lines, high correspondence cost is required. The authors in [19] have suggested a Leader-follower formation that is implemented based on the relative movement states to shape and preserve the formation of multi-robots. The main idea of this strategy is to locate an objective and accurate speed to change the robot's present state. In [20], a virtual leader-follower technique and potential capacities for the formation control and hindrance shirking issue for multi-robot systems. Moreover, in [21] self-ruling ground vehicles have been intended with the end goal that depends on running and bearing data that has been obtained from a forward-looking camera on the Formation control. A visual direction control calculation is planned where continuous picture preparing is utilized to give input signals.

The goal of this paper is to provide a simple explanation of low-cost high accuracy formation control algorithms for a multi-robot system, suitable for unknown areas called leader-neighbor algorithm and neighboring of the leader algorithm. In which a single leader robot controls the formation of the neighbors robots which they are neighbors to it and distributed randomly in unknown environments. The Simulation of navigation multi mobile robots in unknown environments is done by using Visual Basic language. Simulation results show that the mobile robots follows the shortest path and reaches the target. The leader robot localize the other robots by obtaining the lidar signals of each robot and then controlling the distance between each two neighbor robots to obtain a static polygon shape formation. We consider one leader robot and four follower robots each of which is equipped with one RP lidar sensor. The proposed algorithms is described in Section II and III. Simulations results are explained in Section IV. and the conclusions are discussed finally.

II Proposed Leader Neighbor Algorithms

A. Leader-neighbor algorithm

Typically, control over the formation algorithm expects configurable robots to access ideal grading data. In multi-robot systems where it is important to maintain the shape of the formation, the required shape strength will only demonstrate the formation of the group if the neighboring robots have sensors that are perfectly tuned. The leader-follower formation leads to a directed topology that describes the relationships between neighboring robots and analyzes the main characteristics of formation control algorithms such as stability, gravity, and proximity time. When analyzing the distribution of responsibilities between adjacent robots, we find that increasing the number of robots in the team requires additional costs to coordinate all sensor pairs of neighboring robots. This section introduces a new algorithm that controls the formation of multiple robots called the Leader-Neighbor algorithm. This method uses a distance-based algorithm in which the distances between the robots are actively constrained and fixed, and they can be considered recorded together, so the robots are transformed, localized and directed by previous robots. It is imposed in an environment and determines the distance between them. In addition, the next robot direction is restricted according to the rotation of the leader. The investigations of the leader-neighbor algorithm explained in the following steps:

Step1: Leader's alignment stage:

Firstly, in this stage, the robots are distributed randomly. The coordinate axis and the orientation are computed for each robot with respect to the leader one. This posture information can be obtained from the RP lidar sensor which is equipped on each robot. The leader RP lidar sensor will give the orientation and distance information of each robot with respect to the leader position and orientation.

Step2: Circular path drawing for leader's alignment:

In this step we use the orientation of the neighbor robots with respect to the leader one and their orientation to draw the first circular path as described below and shown in Fig1. The neighbors robots scan the environment using their RP lidar sensors and compute their new orientation with respect to the leader one according to the following conditions

If $0 < u_i \leq \pi$ then,

$$u_i = u_i\text{-}j \tag{1}$$

Else if $\pi < u_i \leq 2\pi$ then,

$$u_i = u_i\text{-}j \tag{2}$$

-End if.

Step3: Neighbor's alignment stage:

Neighboring robots are placed in uneven circular tracks in the distance around the leader robot. Initially, a uniform distribution is achieved by changing the direction of the neighboring robots. Then, these robots have to move in a circular path until they are evenly distributed.

Step4: Rearranged the distances among the neighbor robots: A uniform formation of adjacent robots occurs when the angle between any two adjacent robots in relation to the leading robot is the same value. This process is accomplished by calculating the angle ρ between each two adjacent robots and with respect to the leader.

$$\rho = 2\pi / n \tag{3}$$

$$\gamma_i = \tan\text{-}1((y_i - y_o) / (x_i - x_o)) \tag{4}$$

where n is the number of the neighbor robots.

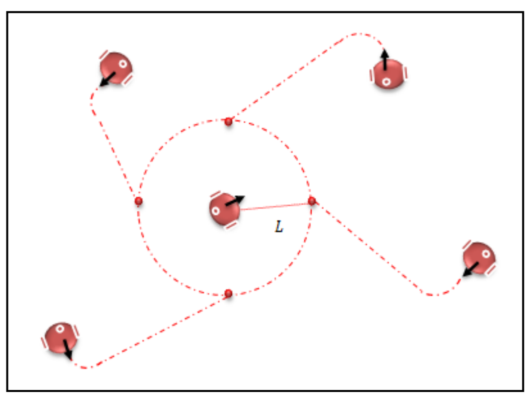


Fig.1 The leader's alignment by the neighbor robots.

Step5: Rearranged the angles between the neighbor robots and the leader one in ascending manner by:

1- Compute the orientation angle between each two neighbor robots.

$$\vartheta_i = \gamma_i + 1 - \gamma_i \tag{5}$$

where ϑ_i is the angle between the robots i and i+1.

2- If the angle ϑ_i is less than the angle ρ then increase the angle γ_i.

$$\gamma_i = \gamma_i + j \quad (6)$$

3- Compute the new position of neighbor robot i.

$$x_{i+1}=x_i+ m*\cos(\gamma_i) \quad (7)$$

$$y_{i+1} = y_i + m*\sin(\gamma_i) \quad (8)$$

4- Repeat for current neighbor robot and for all robots until all the angles between the neighbor robots and the leader one are equal and have the value ρ.

5- Compute the new orientation for the neighbor i and the new position of the neighbor robot i

$$\beta_i = \pi-u_i + \varphi i \quad (9)$$

$$x_{i+1}=x_i + m*\cos(\beta_i) \quad (10)$$

$$y_{i+1}= y_i + m * \sin(\beta_i) \quad (11)$$

6- Repeat 1, 2 and 3 until $R_i = L$ as shown in Fig. 2. Where L represents the formation distance between the neighbors robots and the leader. Where the distance Ri must be computed from the following equation.

$$R_i= \mathrm{sqrt}((y_i - y_o)2+(x_i- x_o)^2) \quad (12)$$

Where j is the increment angle at each step that taken by the robot to reach to the target point. Fig.3 shows the uniform formation of the neighbor robots.

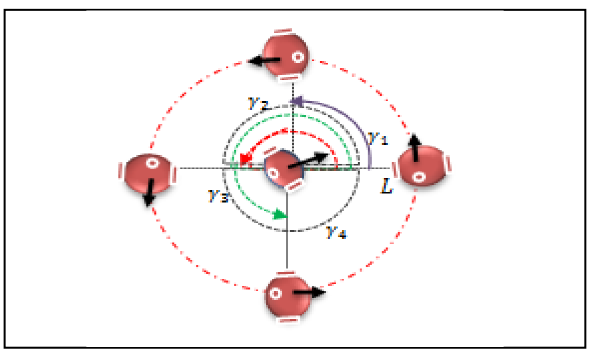


Fig2. neighbor robot i with respect to the leader one.

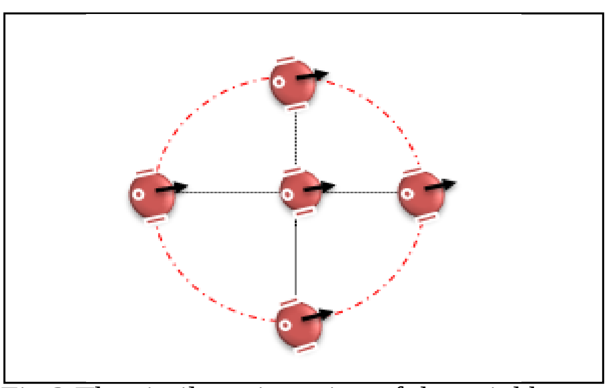


Fig.3 The similar orientation of the neighbor robots with leader.

B. Neighboring of leader algorithm

This section introduces the neighboring of leader algorithm to form a static polygon shape formation. This algorithm is used to predict the paths of neighboring robots depending on the leader's location. It takes into account the monitoring location of the mobile leader robot. First, the positions and orientations of adjacent robots are calculated according to the position of the leader, and in each step of the neighboring robots, the length of the move step increases by a factor (l) until the distance between the neighboring robots equal to the radius of the circle around which the target of each robot around the leader will form a static polygon.

III SIMULATION RESULTS

The new two algorithms (leader–neighbor and neighboring of leader) are simulated to investigate the formation of multi mobile robots using visual basic programming language and tested in Windows environment using an Intel core i5. The different strategies of polygon shape formation are simulated by considering the effect of the connectivity between the neighbor robots and the leader one. Two types of the simulations are implemented on different distribution representing different number of neighbor robots (n) ranging from 3 to 7 robots. The robots were randomly placed on a 500x500 pixels area. For a measureable analysis of this algorithm, we used the following performance metrics:

1. Number of neighbors robots (n): this metric is used to measure the time required to complete the static polygon formation when increasing the number of robots.
2. The formation completing time (t): this metric is used to measure the percentage of the completing time with respect to the number of the neighbor robots.

Fig. 4 (a)–(d) represent the Screenshots of the simulation at different time steps. Fig.4.d represents the final static formation shape in global knowledge environment. The main goal of this simulation is to show the relation between the number of robots and the accomplishment percentage. Fig. 5 shows the second simulation strategy which implemented on different number of neighbor robots (3 to 7 robots) as shown in fig 6,7,8. Fig. 8 shows the comparison between the number of the neighbor robots and the accomplishment percentage. As the number of the robots increase in the environment, the accomplishment percentage is increase. The purpose of these simulation is to compute the time required to complete the formation for different number of neighbor robots. From Fig. 9 we found that as the number of the neighbor robots increase the execution time is increase.

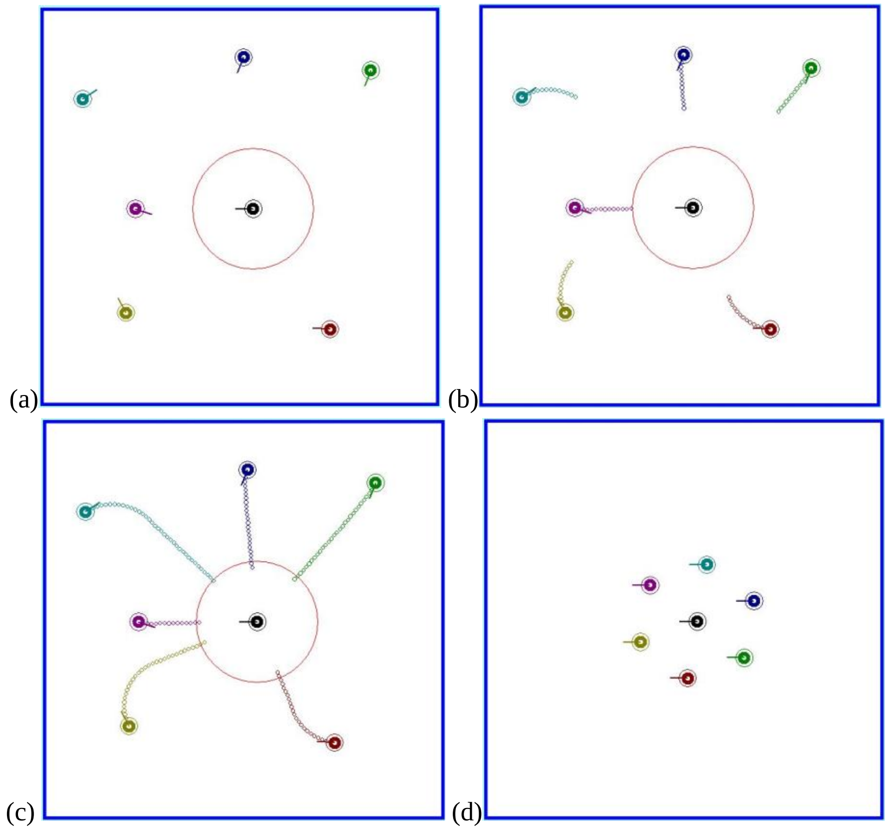


Fig.4 The formation of the robots. (a-d) Screenshots at different time steps using leader-neighbor algorithm.

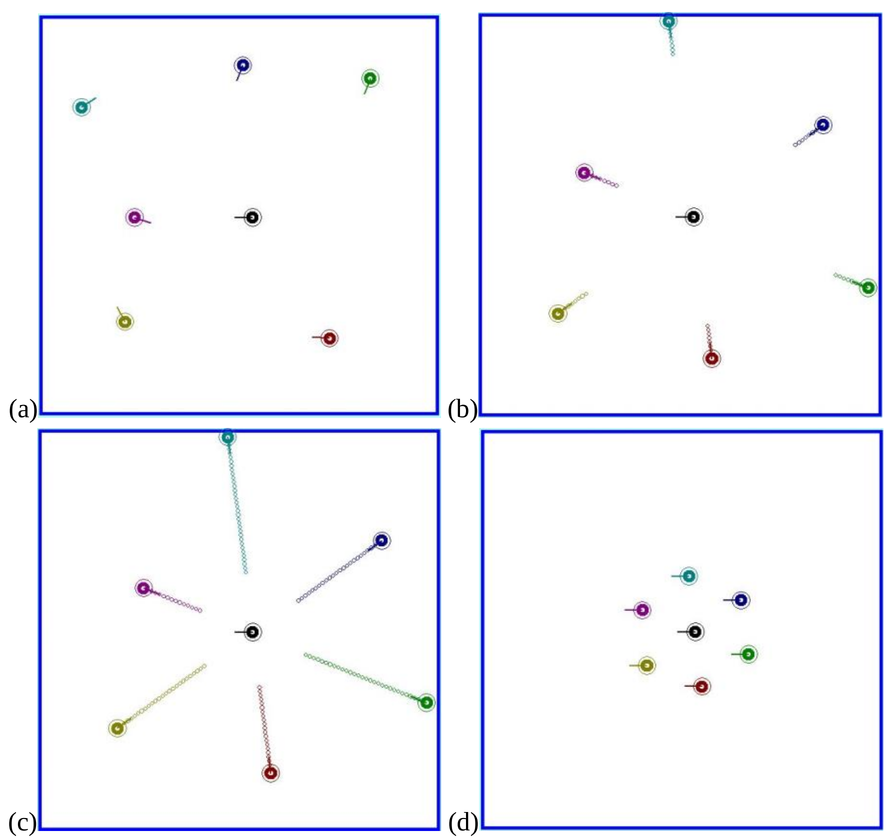
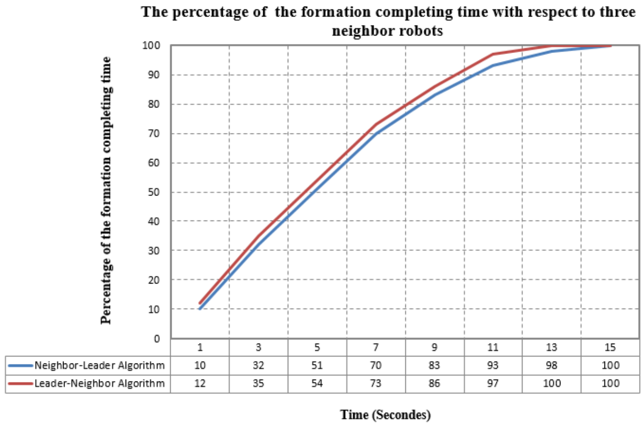
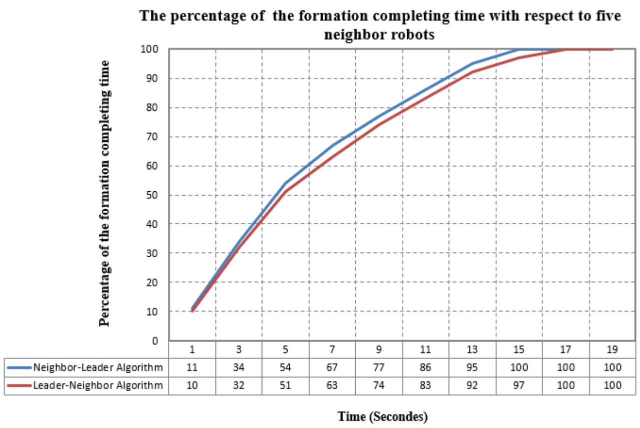


Fig.5 The formation of the robots. (a-d) Screenshots at different time steps using the neighbor-leader algorithm.



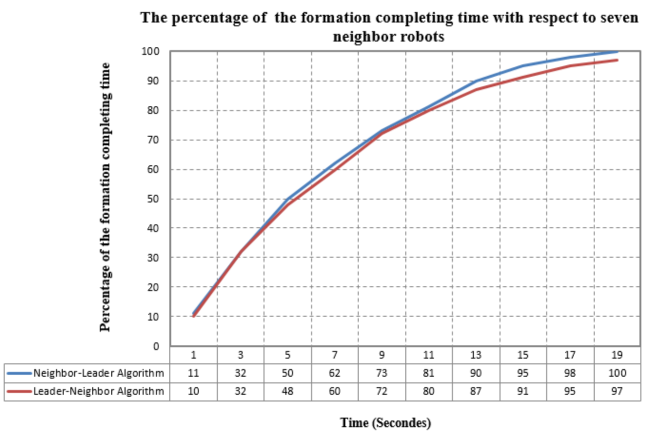
	1	3	5	7	9	11	13	15
Neighbor-Leader Algorithm	10	32	51	70	83	93	98	100
Leader-Neighbor Algorithm	12	35	54	73	86	97	100	100

Fig. 6 Polygon formation for three neighbor robots.



	1	3	5	7	9	11	13	15	17	19
Neighbor-Leader Algorithm	11	34	54	67	77	86	95	100	100	100
Leader-Neighbor Algorithm	10	32	51	63	74	83	92	97	100	100

Fig. 7 Polygon formation for five neighbor robots.

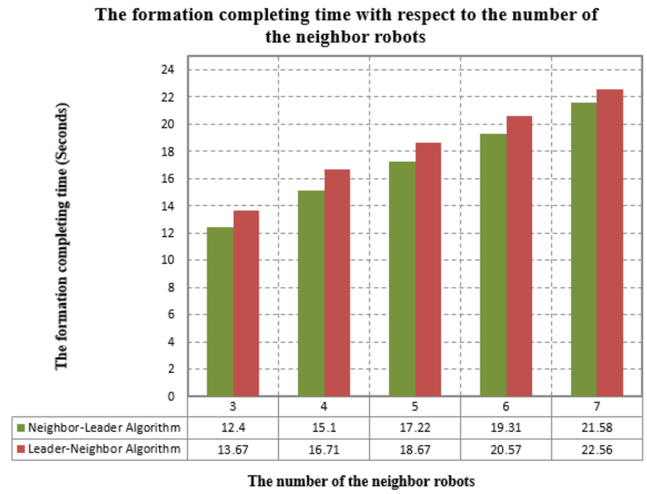


	1	3	5	7	9	11	13	15	17	19
Neighbor-Leader Algorithm	11	32	50	62	73	81	90	95	98	100
Leader-Neighbor Algorithm	10	32	48	60	72	80	87	91	95	97

Fig. 8 Polygon formation for seven neighbor robots.

IV CONCLUSIONS

In this paper, two novel algorithms are proposed to control the a static polygon shape formation in an unknown environment called leader neighbor algorithm and neighboring of the leader algorithm by using several numbers of mobile robots localized and distributed randomly. Simulation results are implemented in an environment with a different number (3 to 7) of robots. The results show that the algorithm have a better efficiency to complete the formation. From results we found that the accomplishment percentage is increases as the number of the neighbor robots increase. Also, as the number of the robots increase the execution time is increase.



	3	4	5	6	7
Neighbor-Leader Algorithm	12.4	15.1	17.22	19.31	21.58
Leader-Neighbor Algorithm	13.67	16.71	18.67	20.57	22.56

Fig. 9 Comparison the time of formation for the two suggested algorithms.

CONFLICT OF INTEREST

The authors have no conflict of relevant interest to this article.

REFERENCES

[1] B. Issa, A. Rashid " RP Lidar Sensor for Multi-Robot Localization using Leader Follower Algorithm" *Iraqi Journal of Electrical and Electronic Engineering*, vol. 15, no.2 ,PP. 2019.

[2] A. Rashid, A. Ali and M. Frasca " Polygon Shape Formation for Multi-Mobile Robots in a Global Knowledge Environment" *Iraqi Journal of Electrical and Electronic Engineering* Vol. 15, No.1, 2019.

[3] A. Rashid and A. Ali, " Polygon Shape Formation for Multi-Mobile Robots in a Local Knowledge Environment" *Basrah Journal of Engineering Scinces* Vol. 19, No.2 – 2019.

[4] Guo,J.; Lin, Z.; M. Cao, Z. et.al. Adaptive Leader-Follower Formation Control for Autonomous Mobile Robots" *American Control Conference, Marriott Waterfront*, Baltimore, MD, USA, July 02, 2010.

[5] A. Tews, M. Matari, G.Sukhatme, "Avoiding Detection in a Dynamic Environment" *The International Conference on Intelligent Robots and Systems*, Sendai, Japan, 2004.

[6] J. Toibero, F. Roberti, R. Carelli, P. Fiorini "Formation Control for Non-Holonomic Mobile Robots: A Hybrid Approach" *Multi-Robot, Systems Tech Education and Publishing in Vienna*, Austria, pp. 326, May 2008.

[7] R. Zhao, H. Lee, "Fuzzy-based Path Planning for Multiple Mobile Robots in Unknown Dynamic Environment" *JEET*, Vol. 12,No. 2, PP. 918-925 2017.

[8] J. Mora, E. Montijanoy, et.al "Distributed Multi-Robot Formation Control among Obstacles" *A Geometric and Optimization Approach with Consensus the MIT-Singapore Alliance for Research and Technology*.2013.

[9] H. Yang, X. Bao, et al. "A Multi-Robot Formation Platform based on an Indoor Global Positioning System" *Appl. Sci*. 2019.

[10] T. Nascimento, F. Fontes, "Leader Following Formation Control For Omnidirectional Mobile Robots" *The International Conference on Informatics in Control, Automation and Robotics ICINCO*, PP.135-144, 2011.

[11] G. Gamage, G. Mann, R. Gosine, "Leader follower based formation control strategies for non-holonomic mobile robots Design" *Implementation and Experimental Validation American Control Conference*, Marriott Waterfront, Baltimore, MD, USA June 30-July 02, 2010.

[12] O. Hachour "The proposed path finding strategy in static unknown environments" *International Journal Of Systems Applications" Engineering & Development*, no 4, vol. 3, 2009.

[13] Wang, Yuanzhe "Multi-robot formation control in obstacle environments" This document is downloaded from *DR-NTU, Nanyang Technological University Library*, Singapore, 2019-02-19.

[14] A. Solot, A. Ferlini " Leader-Follower Formations on Real Terrestrial Robots" *Association for Computing Machinery*, Beijing, China,19 August, 2019.

[15] T. Soleyman and F. Saghafi "Behavior-based acceleration commanded formation flight control", *International Conference on Control, Automation and Systems* IEEE, 17 December 2010.

[16] J. R T. Lawton, R.W. Beard and B.J. Young "A decentralized approach to formation maneuvers", *IEEE Transactions on Robotics and Automation*, Vol. 19, No. 6 , Dec. 2003.

[17] L. Barnes, M.David Fields, and K. P. Valavanis "Unmanned ground vehicle swarm formation control using potential field" *Mediterranean Conference on Control* 2007.

[18] Y. Zhao, Y. Zhang, and J. Lee "Lyapunov and Sliding Mode Based Leader-follower Formation Control for Multiple Mobile Robots with an Augmented Distance-angle Strategy" *International Journal of Control, Automation and Systems* vol.17, no.5, PP. 1314-1321, 2019.

[19] Y. Dai, V. Tran, et al "Leader-Follower Formation Control of Multi-robots by Using a Stable Tracking Control Method" *Conference Paper· Springer-Verlag Berlin Heidelberg* June 2010.

[20] J. Yan, X. Guan, et al "Formation Control and Obstacle Avoidance for Multi-Agent System-Based Virtual Leader-Follower Strategy" International journal of Information Technology and Decision Making. Vol.16,No.03,PP. 865-880 in 2017.

[21] S. He, M. Wang, et al "Leader–Follower Formation Control of USVs With Prescribed Performance and Collision Avoidance" *Journals & Magazines: IEEE Transactions on Industrial* vol. 15, PP. 572 – 581, 23 May 2018.