

Consensus-Based Obstacle Avoidance for Robotic Swarm System with Behavior-Based Control Scheme

Ji-Wook Kwon¹, Jin Hyo Kim^{1,2}, and Jiwon Seo^{1,2*}

¹ Yonsei Institute of Convergence Technology, Yonsei University,
Incheon, 406-840, Korea (bluemichael@yonsei.ac.kr; jinhyo.kim@yonsei.ac.kr; jiwon.seo@yonsei.ac.kr)

² School of Integrated Technology, Yonsei University,
Incheon, 406-840, Korea (jinhyo.kim@yonsei.ac.kr; jiwon.seo@yonsei.ac.kr) * Corresponding author

Abstract: This paper proposes the consensus algorithm for obstacle avoidance behavior of a robotic swarm system such that the orientations of all the robots are converged to consented value of them. In the previous robotic swarm algorithms based on a behavior based control has contended with obtaining the routes of the robots when accomplishing objectives such as aggregation, dispersion, or homing. In this paper, the robots move with smooth path by the proposed consensus algorithm. This advantage can lead to reduce the moving distance and the moving cost. Finally, simulation results are included to demonstrate the performance of the proposed algorithm for the robotic swarm system based on the behavior-based control with consensus algorithm for obstacle avoidance.

Keywords: Robotic swarm, consensus, obstacle avoidance, behavior based control

1. INTRODUCTION

Robotic swarm has interested as an approach of multiple robot control system while a multi-agent system has been expected as a solution of the problem of the single robot system. Swarm robotics has been regarded as “*the systematic application of scientific and technical knowledge to model and specify requirements, design, realize, verify, validate, operate, and maintain a swarm intelligence system*” [1], and also, this swarm of the multiple robots has a large area to research. This robotic swarm system is commonly controlled by behavior based control scheme [1-5].

To control multiple robot system in a simple way and reuse the algorithms and their code [6], the behavior based control scheme has been employed to the robotic swarm system [2-5]. However, in the behavior base control scheme where the behaviors of each robot are combinations of basic behaviors [4], the robots can have irregular movement (e.g., a complex motion (refer the results in [4] and following Fig. 5 (a)). In particular, obstacle avoidance behavior (in [4], safe wandering) is the significant behavior achieving the safety of each robot against a collision with obstacles. In literature, if the obstacles approach to a robot, to avoid the collision, the avoidance behavior should have been assigned the highest priority without considering the other robots. This emerges that, even though each robot is included multiple robot system, it operates independent on other robots. However, this independent avoidance behavior can derive the irregular and independent movement without regarding the other robots, thus, the moving cost (i.e., a moving distance) can increase.

Considering the communication between robots, it is possible that, since the avoidance behavior of the robots facing the obstacles can inform the existence of the obstacle, whereas they do not face threatening obstacles, they can turn to avoid the obstacles in advance. This group motion can be shown in groups of animals including a school of fish and a flock of birds [7-9]. In

the group of the animals, the group motions are achieved the consensus and synchronization with the motions of the neighbors.

Thus, we propose the avoidance algorithm based on the consensus on the avoidance behaviors to inform the avoidance situation to the other robots. By the proposed consensus algorithm, the robots can avoid against the obstacles beforehand using the reflected information of the obstacle from the robots facing the obstacle. To realize the consensus on the behaviors in the robotic swarm system, we use the consensus of the orientation angle of the robots. First, we acquire the combined behavior from the basic behavior to achieve the control objectives, second, the combined behaviors of the robots are exchanged between robots in communication range, and finally, the behaviors are reached consensus by the proposed consensus algorithm.

The robotic swarm system with the proposed consensus algorithm has the advantages as follows. The movements of robots become smooth and simple, and also, the moving distance is reduced, thus, the cost of the movement of each robot can be reduced.

2. SYSTEM DESCRIPTION AND ASSUMPTIONS

In this paper, the robotic swarm system with the wheeled mobile robot describing as following kinematic model:

$$\begin{bmatrix} \dot{x}_i \\ \dot{y}_i \\ \dot{\theta}_i \end{bmatrix} = \begin{bmatrix} \cos \theta_i & 0 \\ \sin \theta_i & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v_i \\ \omega_i \end{bmatrix} \quad (1)$$

where (x,y) is the position of the robot, θ is the orientation angle, v and ω are linear and angular velocities, respectively, and a subscript i is an index of the robot. We assume that the member robots equip the

obstacle detecting sensors and wireless communication device as depicted in Fig. 1. As can be seen in Fig. 1, the robots acquire the information of other robots via the wireless communication devices, and then, they construct the network with the undirected communication graph. To deliver the information to other robots, we consider the two cases (the description of each strategy will be followed): (a) the communication with all the robots and (b) the communication with the neighbor robots.

3. CONSENSUS ON ORIENTATIONS

To improve the performance of the obstacle avoidance and reduce motion load of the member robots, this section proposes the two types of consensus algorithm for controlling the orientation of the robots. Consider the cases that each robot can access the information of all the robots, on the other hand, the robots can communicate with the adjacent robots. These two cases are depicted in Figs. 2 and 3.

3.1 Consensus on orientations of all the robots

The case that all robots can access the information of all the robots is presented in Fig. 2. In Fig. 2, the dotted lines show the connections between robots. From the communication strategy in Fig. 2, the robots can directly reach the consensus on the orientation as follows.

$$\theta_i^c = \sum_{j=1}^n k_j \theta_j \quad (2)$$

where n is the number of the robots and k_j is a positive constant. Here, we choose $k_j = 1/n$ in this paper, that is, the orientations of all the robots are converged to mean value of all the robots.

3.2 Consensus of orientations of neighbors

In the second case, the robots communicate with the adjacent robots which are in a communication range as depicted in Fig. 3. To make orientation of the robots converge to same value using the local information, we modify (2) as follows.

$$\theta_i^c = \sum_{j \in C} k_j \theta_j \quad (3)$$

where C is the set of the adjacent robots and we choose $k_j = 1/m$ where m is the number of the robots in C .

4. SYSTEM IMPLEMENTATION USING BEHAVIOR BASED CONTROL

To employ the proposed consensus of member robots for the obstacle avoidance, we use the behavior based formation control strategy, and also, the four behaviors in [2-5] are used: homing, aggregation, dispersion, and avoidance. Whereas outputs of the behaviors in

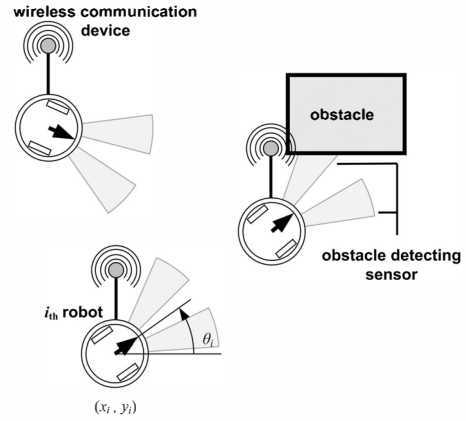


Fig. 1 The robots organizing the swarm system

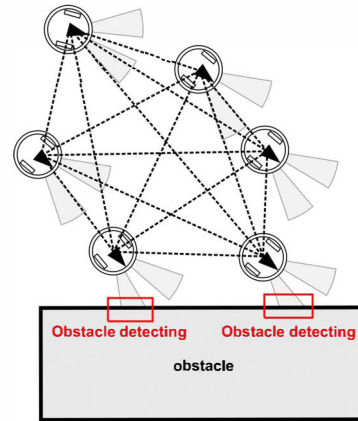


Fig. 2 The robots connected with all the other robots.

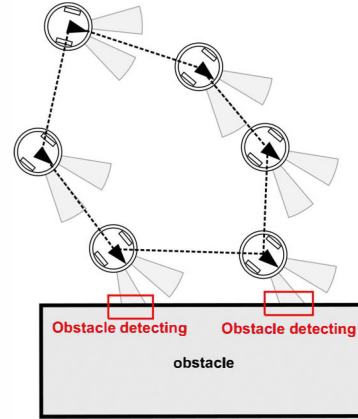


Fig. 3 The robots connected with the adjacent robots which are in the communication range.

literature are control inputs such as the linear and the angular velocities, in this paper, the outputs of the behaviors are modified from the control inputs to the desired orientations as in following Behaviors.

Behavior 1. Homing

$$\theta_d^h = \text{atan2}(e_y^h, e_x^h)$$

where $e_x^h = x_h - x$, $e_y^h = y_h - y$, and (x_h, y_h) is the home position.

Behavior 2. Aggregation

$$\theta_d^a = \text{atan2}(e_y^a, e_x^a)$$

where $e_x^a = x_a - x$, $e_y^a = y_a - y$, (x_a, y_a) is the desired position to acquire the aggregation, and $x_a = \text{mean}(x_j, x)$, $y_a = \text{mean}(y_j, y)$ where (x_j, y_j) is the position of the farthest robot of the connected robots.

Behavior 3. Dispersion

$$\theta_d^d = -\text{atan2}(e_y^d, e_x^d)$$

where $e_x^d = x_d - x$, $e_y^d = y_d - y$, (x_d, y_d) is the desired position to acquire the aggregation, and (x_d, y_d) is the position of the mean of the two nearest robots of the connected robots.

Behavior 4. Avoidance

$$\theta_d^v = \begin{cases} \theta - \pi/4 & \text{left obstacle} \\ \theta + \pi/4 & \text{right obstacle} \end{cases}$$

where θ is the current orientation.

These behaviors are combined by the weighted vector sum as depicted in Fig. 4. In Fig. 4, the weighting factors, $w1-w4$, are ratio of each behaviors, Σ is the weighted vector summation of the direction vectors which are the outputs of the basic behaviors, and θ_i^b is the desired orientation angle which is the combination of the basic behaviors.

This combination of the behaviors is combined with the proposed consensus algorithm as follows.

$$\theta_i^d = w_c \theta_i^c + (1 - w_c) \theta_i^b$$

where $|w_c| \leq 1$ is the weighting factor. Also, the linear velocities of the robots are determined as constant value as $v_i^d = v_d$. It can be noted that it can be assumed that desired motion (v_i^d, θ_i^d) can be realized by the dynamic control law such as [10-12].

4. SIMULATION RESULTS

To show the performance of the proposed consensus of the orientation of the robots, the following scenario is employed. 26 robots whose initial positions are

$$\begin{cases} x_i(0) = \cos(2(i-1)\pi/n) + 6 \\ y_i(0) = 2.5 \sin(2i\pi/n) + 4 \\ \theta_i(0) = \pi/2 \end{cases}$$

where n is the number of the robots are used, the home position is $(x_h, y_h) = (9, 18)$, and the linear velocity of the robots is $v_i = 0.4$ (m/s). The simulation results of

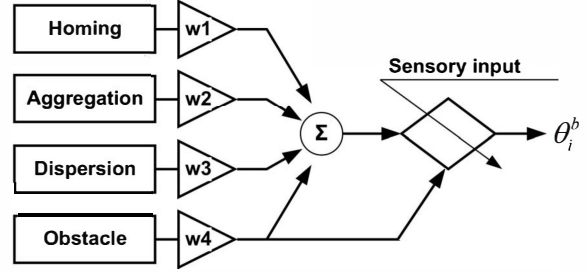
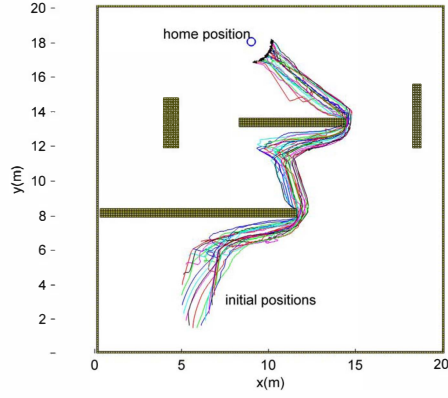


Fig. 4 Combination of the basic behaviors.

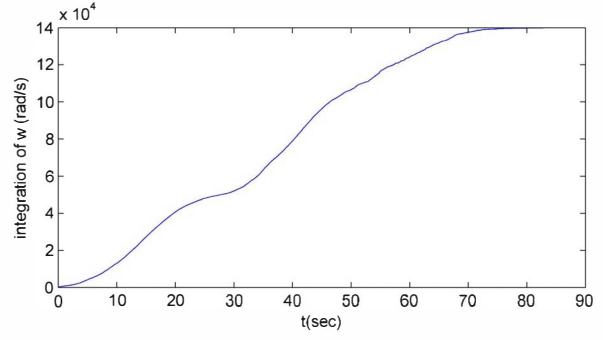
the robot swarm system using the consensus algorithms in (2) and (3) are shown in Fig. 5, also, the route of the robotic swarm using the combined behavior without the consensus algorithm in (2) and (3) is shown in Fig. 5 (a) to compare the performance of the proposed algorithm. As can be seen in Fig. 5 (a), the robots in the robotic swarm system move while showing the complex routes to maintain the objectives of the behaviors (homing, aggregation, dispersion, and obstacle avoidance), and thus, these complex routes with many instantaneous turning motions emerge the high motion load, increase of the moving distance and the moving cost. On the other hand, as in Figs. 5 (b) and (c), the routes of the robots with the proposed consensus algorithm show the smooth and simple motions. In Fig. 5 (b), the movements of the robots which do not detect the obstacle show the turning motion since the consensus of the orientation information with all the robots. In Fig. 5 (c), the robots show the similar movements to the routes in the Fig. 5 (b) in spite of the consensus based on the local information. The proposed consensus algorithms make the complex motions in Fig. 5 (a) the smooth and simplified motions. Also, in the case of consensus of the local information as in (3), the robots move while maintaining the smooth and simplified movements. It can be noted here that the performance of the consensus algorithm based on the local information in (3) is similar to the robotic swarm system with the global information in (2), but, the effects of the consensus algorithm can be reduced. In addition, in Figs. 5(d)-(f), the moving costs of the three cases are depicted. The cost representing the moving loads is described as accumulation of angular velocities. As can be seen in Figs. 5(d)-(f), the moving costs of the swarm system with the proposed consensus algorithm is reduced (in Figs. 5(d) and (f)) then the case without the consensus algorithm (Fig. 5(e)).

5. CONCLUSION

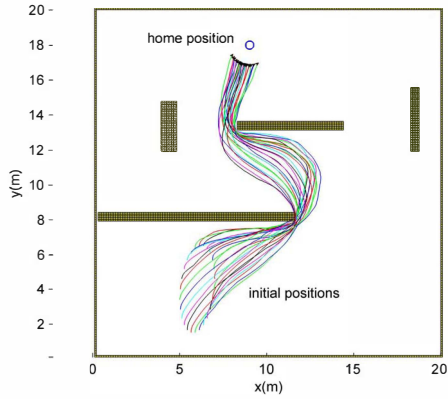
We addressed the consensus of the orientation for the robotic swarm system. By the proposed algorithm with the two cases based on the global and local information, the orientation angles of the robots in the system converge to same value, and thus, this consensus algorithm reduce the cost of the movement and increase the safety against the collision with the obstacles. The performance of the proposed consensus algorithm was shown by the numerical simulation results.



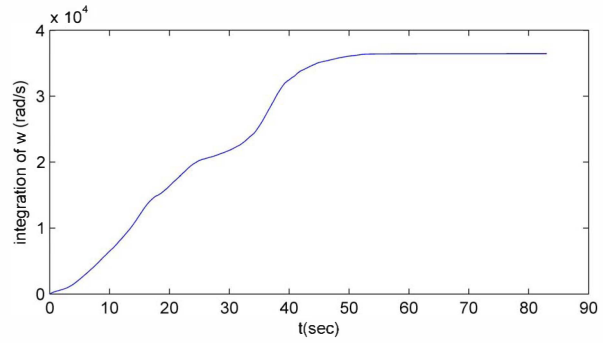
(a) the routes of the robots without the proposed consensus algorithm



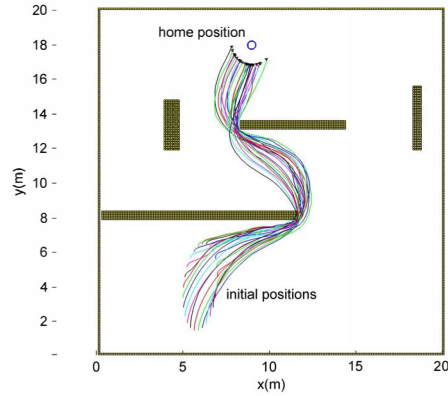
(d) The moving cost of the robots without the proposed consensus algorithm



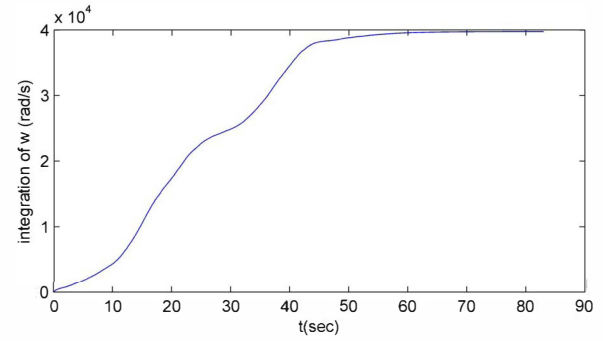
(b) the routes of the robots with the proposed algorithm in (2)



(e) The moving cost of with the proposed algorithm in (2)



(c) the routes of the robots with the proposed algorithm in (3)



(f) The moving cost of with the proposed algorithm in (3)

Fig. 5. The simulation results

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REFERENCES

- [1] M. Brambilla, E. Ferrante, and M. Birattari, "Swarm robotics: a review from the swarm engineering perspective," *Swarm Intelligence*, vol. 7, no. 1, pp. 1-41, Mar. 2013.
- [2] B. G. Woolley and G. L. Peterson, "Unified behavior framework for reactive robot control," *Journal of Intelligent and robotics systems*, vol. 55, no. 2-3, pp. 155-176, 2009.
- [3] T. Balch and R. C. Arkin, "Behavior-based

- formation control for multirobot teams,” *IEEE Transactions on Robotics and Automation*, vol. 14, no. 6, Dec. 1998.
- [4] M. J. Mataric, *Interaction and intelligent behaviors*, MIT EECS PhD Thesis, May 1994
 - [5] J.-W. Kwon, S.-K. Hong, and D. Chwa, “Environment monitoring algorithm using behavior-based multiple robot system,” *The Transactions of the Korean Institute of Electrical Engineers*, vol. 61, no. 4, pp. 622-628, APR. 2012, In Korean.
 - [6] B. G. Woolley and G. L. Peterson, “Unified behavior framework for reactive robot control,” *Journal of Intelligent and robotics systems*, vol. 55, no. 2-3, pp. 155-176, Jul. 2009.
 - [7] C. K. Hemelrijk and H. Hildenbrandt, “Schools of fish and flocks of birds: their shape and internal structure by self-organization,” *Interface Focus*, vol. 2, no. 6, pp. 726-737, Dec. 2012.
 - [8] S.-Y. Jung and M. A. Goodrich, “Multi-robot perimeter-shaping through mediator-based swarm control,” *Proceedings of International Conference on Advanced Robotics*, 2013, Uruguay, Nov. 2013.
 - [9] S.-H. Lee, “Predator’s attack-induced phase-like transition in prey flock,” *Physics Letters A*, vol. 357, no. 4-5, pp. 270-274, Sep. 2006.
 - [10] G. Oriolo, A. D. Luca, and M. Vendittelli, “WMR control via dynamic feedback linearization: design, implementation, and experimental validation,” *IEEE Transactions on Control System Technology*, vol. 10, no. 6, pp. 835-852, Nov. 2002.
 - [11] D. Chwa, “Tracking control of differential-drive wheeled mobile robots using a backstepping-like feedback linearization,” *IEEE Transactions on System Man and Cybernetics, Part A*, vol. 40, no. 6, pp. 1285–1295, Nov. 2010.
 - [12] J.-W. Kwon and J. Seo, “Docking control on both stationary and moving stations based on docking formation,” *Electronics Letters*, vol. 50, no. 6, pp. 436-438, Mar. 2014.