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Research Article

New Pigeon Flocks Behavior Used for Multiple Robots Autonomous Formation

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Abstract

Background: Generally, robots are developing towards to system application, which has been becoming a hot issue. However, a single robot cannot better accomplish tasks and multiple robots cannot cooperate with each other to accomplish works. How to make robots more better collaboratively complete the task is a problem. Multiple robots autonomous formation has the similarity to pigeon flocks behavior mechanism in biology swarm intelligence algorithms. **Materials and Methods:** Therefore, this study proposes a multiple robots autonomous formation based on pigeon flocks behavior method in this study. The new method includes three steps. Firstly, it builds pigeon flocks behavior mechanism model by imitating specific level behavior in pigeon flocks. Secondly, topology structure and leadership mechanism in pigeon flocks are modeled by adopting directed graph and artificial potential field theory based on the existed pigeon flock models. Thirdly, after deep analysis on robots autonomous formation, it designs a multiple robots autonomous formation controller based on pigeon flocks behavior method. This controller is designed with pigeon flocks behavior as the core, which contains two auxiliary parts: Control instruction solver and state transformer. **Results:** Finally, simulation experiments show that multiple robots autonomous formation can form desired formation with this method. **Conclusion:** Multiple robots autonomous formation based on pigeon flocks behavior is an effective method, which can effectively improve the quality of robots autonomous formation.

Key words: Robots autonomous formation, pigeon flocks behavior mechanism, topology structure, directed graph, artificial potential field theory

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INTRODUCTION

Currently, robots coordinated control[1] has become one of hot issues in multiple robot system. Multiple robots can complete some tasks that single robot cannot solve through coordination control[2], which usually has a higher efficiency. Formation control is a typical multi-robot coordination problem which has widely been used in geological survey[3], reconnaissance, rescue, mine clearance[4] and transportation and other fields. At present, the multi-robot formation control algorithm mainly includes the method based on behavior[5], virtual structure method[6] and pilot follow method[7].

Lima *et al.*[8] presented a formation control loop that maximized the performance of the cooperative perception of a tracked target by a team of mobile robots. Sun and Anderson[9] proposed two control approaches, one with centroid invariance and the other without preserving invariant formation centroid, which contained commonly-used gradient descent control for shape stabilization and an additional term to control the directions of certain relative position vectors associated with some chosen agents. Morozova[10] put forward a virtual leaders-based approach that ensured automatic changes in formation shape in the process of executing a mission with the establishing or loss of connection with a consecutive agent, along with full interchangeability of agents and presence of measurement noises. Through analyzing biological systems behaviors, it gets inspiration. Swarm intelligence motivation has been applied on multiple robots autonomous formation. So, this study introduces pigeon flocks behavior into robots autonomous formation based on the existed intelligence model.

Pigeons have amazing navigation ability, unique eyes layout and wonderful group flight mechanism. So many researchers study on pigeons. On the aspect of navigation sense, Beason and Wiltschko[11] found that magnetic field information influenced pigeon navigation in ways that were consistent with magnetic map components. Whiten[12] showed that height of sun would also affect the pigeon navigation. Therefore, Duan and Qiao[13] proposed a new intelligence method Pigeon-Inspired Optimization (PIO). The PIO represents good performance for solving optimization problems.

In this study, it makes model for the specific hierarchies behavior in pigeon flocks mechanism based on Vicsek model and A/R model, which includes two steps. First, directed graph is used to describe a pigeon flocks topology structure and it builds a pigeon flocks hierarchy model, second, artificial potential field method is chosen to illustrate edge set of directed graph in pigeon flocks. Then, the new model is applied into multiple robots autonomous formation. Through this design, it can effectively improve the quality of robots autonomous formation. The main contribution of this study is as follows:

- It makes new pigeon flocks model by adopting directed graph and artificial potential field theory
- New pigeon flock model is the first time used for multiple robots autonomous formation

MATERIALS AND METHODS

Pigeon flocks behavior mechanism: There is a strict hierarchy relationship between different individuals in pigeon behavior mechanism. The normalized speed inner product can express the speed correlation among pigeons. The size of speed inner product will judge the head pigeon at different time. Pigeons leadership is not similar to wolves and other land group model. In that the following pigeons have hierarchy except head pigeon. Head pigeons are in an absolute leadership position, rest following pigeons obey upper pigeons. But they cannot influence upper pigeons.

Aiming at the above pigeon behavior mechanism, it builds mechanism model from hierarchical structure and leadership function.

Pigeon flocks hierarchies model based on graph theory: The pigeon flocks hierarchies can be describes by directed graph: D = (V, E). The n pigeons: $V = \{v_1, v_2..., v_n\}$ and edge set $E = \{e_1, e_2,..., e_m\}$ is the leadership function line of upper pigeon on lower pigeon. The N_i is the upper pigeons set with leadership function on pigeon i by Eq. 1:

$$N_i = \{j, k,...\} \subseteq \{1, 2,..., n\} \tag{1}$$

It can stipulate the every pigeon hierarchy and the range of upper pigeon leadership. Imitating the true hierarchy structure in pigeon flocks, it gets the pigeon flocks hierarchy structure directed graph as Fig. 1.

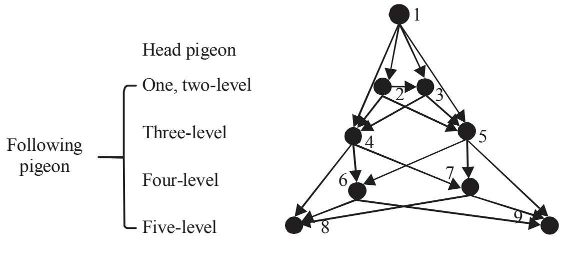

Fig. 1: Pigeon flocks hierarchy structure directed graph

Denotes pigeons, namely vertex set in directed graph. denotes leadership between pigeons, namely edge set. Assuming that the rest levels only have two pigeons except one level (one pigeon) and two level (one pigeon). One level is in the charge of head pigeon and two level is in the charge of head pigeon and one level. So, the leadership in pigeons can be expressed by N_i in Eq. 2:

$$N_i = \begin{cases} \varphi, & i=1 \\ 1, & i=1 \\ 1,\ 2, & i=3 \\ 1,\ 2,\ 3, & i=4 \\ i-4,\ \ i-2,\ \ i-1, & i=2k,\ k=(3,4,\ldots) \\ i-3,\ i-2,\ i-1, & i=2k+1,\ k=(2,3,\ldots) \end{cases} \tag{2}$$

In this study, it assumes that multiple robots move just like pigeon flocks formation flying. The leadership relation has an effect on gathering, collision avoidance and stable at stipulated spacing. Figure 2 show the leadership of head pigeon on one-level following pigeon. It takes head pigeon as center and finds the stable point on the circumference of circle. The distance between head pigeon and one-level is as radius.

The stable position of one-level pigeon has many possibilities. When one-level pigeon is fixed, the position of two-level pigeon has two possibilities as Fig. 2. When position of one, two-level pigeons is fixed, pigeon flocks formation is unique.

Pigeons leadership model based on artificial potential field method: In pigeons, upper pigeons lead the lower pigeons avoiding collision and trying to keep gather, match their speed. Because robots move in two-dimension, assuming that pigeons fly in two-dimension space. The dynamic model of each pigeon is in Eq. 3:

$$\begin{cases} X^i = v^i, \\ m^i v^i = u^i - k^i v^i \end{cases} \tag{3}$$

where, $X^i \in R^2$, i = 1, 2,..., n, $v^i \in R^2$ is the velocity vector of t-th pigeon, $m^i>0$ is mass of t-th pigeon, $u^i \in R^2$ is control input, $-k^i v^i$ is velocity damping. The $k^i>0$ is speed attenuation gain. The $X^{ij} = X^i - X^j$ is relative position vector between pigeon i and j.

The u^i can be expressed by Eq. 4:

$$u^i = \alpha^i + \beta^i + \gamma^i + k^i v^i \tag{4}$$

where, α^i is artificial potential field control component to keep space among pigeons, β^i is the same speed control component of i-th pigeon with upper pigeon and γ^i is speed of i-th pigeon towards to expected velocity.

Potential function between i-th pigeon and j-th upper pigeon is shown in Eq. 5:

$$P^{ij}(\| X^{ij} \|) = \ln \| X^{ij} \|^2 + \frac{d_{ij}^2}{\| X^{ij} \|^2} \tag{5}$$

where, d_{ij} is the expected distance between i-th pigeon and j-th upper pigeon.

The controlled quantity $u_{1,2}^i$ of i-th following pigeon is two-dimension. And is given by Eq. 6:

$$u_{1,2}^i = (-K_p \sum \nabla_{\|X_{1,2}^{ij}\|} P^{ij} - K_v \sum (v_{1,2}^i - v_{1,2}^j) - m^i (v_{1,2}^i - v_{1,2}^j)) w_1 + k^i v_{1,2}^i \tag{6}$$

where, $K_v>0$ is velocity feedback gain factor, $K_p>0$ is artificial potential field gain factor and w_1 is controlled quantity adjustment factor.

Muitiple robots autonomous formation based on pigeon flocks behavior: The pigeons hierarchy behavior has a great inspiration on multiple robots autonomous formation. Firstly, pigeons leadership behavior is different with other general single land group behavior. They need cooperative work just like robots. Secondly, not every pigeon has relationship, they has strict hierarchy. The contact way between individual and the group is not unique. This new model is applied into multiple robots autonomous formation, which not only saves space but can guarantee reliability of robots.

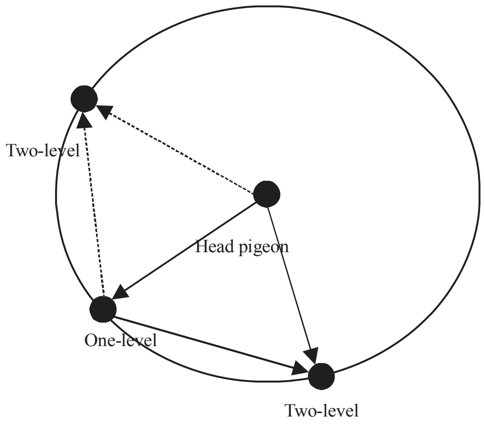

Fig. 2: Pigeon flocks formation process

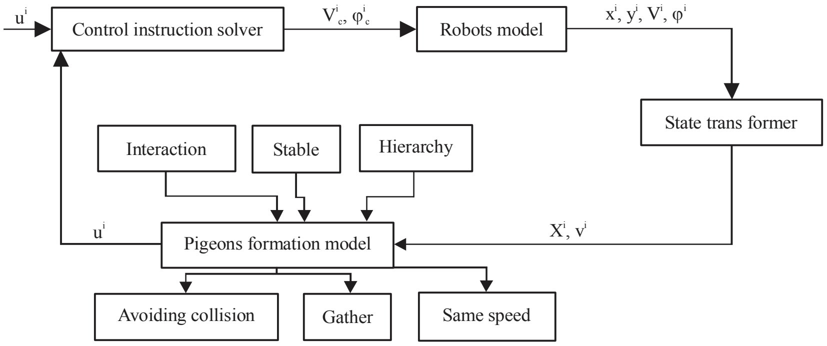

Fig. 3: Sight-interface mapping relation

Robots autonomous formation model: Assuming that robot has speed and direction angle parameters as follows in Eq. 7:

$$\begin{cases} x^i = V^i \cos\varphi^i,\ y^i = V^i \sin\varphi^i, \\ \hat{V}^i = \dfrac{1}{\tau_v}(V_c^i - V^i),\ \hat{\varphi}^i = \dfrac{1}{\tau_\varphi}(\varphi_c^i - \varphi^i) \end{cases} \tag{7}$$

where, (x^i, y^i) is the position of robot, V_i and φ^i are speed and direction angle respectively, V_c^i and φ_c^i are control input and τ_v and τ_φ are time constant.

Multiple robots autonomous formation: The formation includes four parts: Two main body parts, pigeons formation model, robots model and two auxiliary links (Control instruction solver and state transformer) as Fig. 3.

In Fig. 3, control instruction solver transmits the input u^i into two control input V_c^i and φ_c^i as follows in Eq. 8:

$$\begin{cases} V_c^i = \tau_v\ (u_1^i \cos\varphi^i + u_2^i \sin\varphi^i) + V^i \\ \varphi_c^i = \dfrac{\tau_\varphi}{V^i}\ (u_2^i \cos\varphi^i - u_1^i \sin\varphi^i) + \varphi^i \end{cases} \tag{8}$$

State transformer transmits state input $(x^i, y^i, V^i, \varphi^i)$ into (X^i, v^i) in pigeon formation model as follows Eq. 9:

$$\begin{cases} X^i = (x^i, y^i) \\ v^i = (V^i \cos\varphi^i,\ V^i \sin\varphi^i) \end{cases} \tag{9}$$

And the detailed process of multiple robots autonomous formation is:

Step 1: Given the current robot input u^1, use Eq. 8 and 9 to get robot state (X^1, v^1)

Step 2: Analogy pigeons hierarchy topological structure, use Eq. 2 to get upper set N_i of following robot i

Step 3: Next state output of N_i is (X^{N^i}, v^{N^i}). Through pigeon hierarchy, it can get the next time control input u^i by using Eq. 6 and 7

Step 4: Using Eq. 9 gets control input V_c^i and φ_c^i

Step 5: Using Eq. 8 gets the i-th robot true state of next time $(x^i, y^i, V^i, \varphi^i)$

Step 6: State is transformed into (X^i, v^i) and as input for pigeons behavior

Step 7: Return step 1 until reaching to stop condition

RESULTS AND DISCUSSION

In this experiment, the parameters are as follows. The $\tau_v = 5$ sec is time constant, $\tau_\varphi = 1$ sec is direction angle time constant. Range of velocity is 1 and 5 m min^{-1}. The $K_v = 1$, $K_p = 160$, $w_1 = 0.1$, $w_2 = 1$. Robot hierarchy parameters are as Table 1. Artificial potential field parameters are as Table 2. Experiment time is 1200 sec. Sampling time is 300 sec.

Formation trajectory is as Fig. 4-6. Head robot is robot 1. Following robots is robot 2, robot 3, robot 4 and robot 5, they can complete formation with a small error in a short time. So it shows that the new model has good dynamic performance and has high formation accuracy. Figure 5 and 6 is the robots movement path at t = 300 and 600 sec, respectively.

In this experiment, it is divided into three stages. First stage, robots move along with a circle as Fig. 4. They can keep perfect formation with pigeon model. Second stage, when there is a certain direction angle, robots can move with soigne formation from 0-300 sec as Fig. 4. Third stage, robots walk with a straight line, the formation is the best.

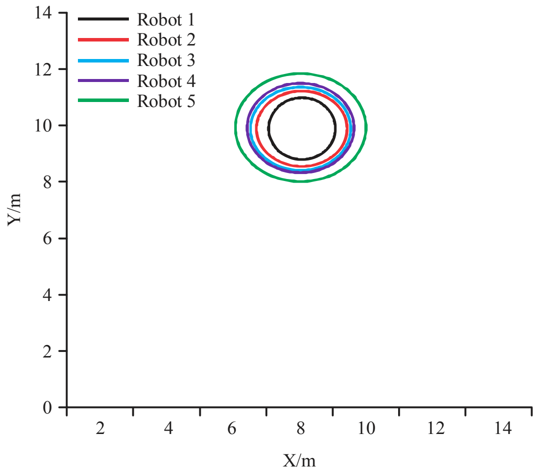

Fig. 4: Robots formation path with a circle

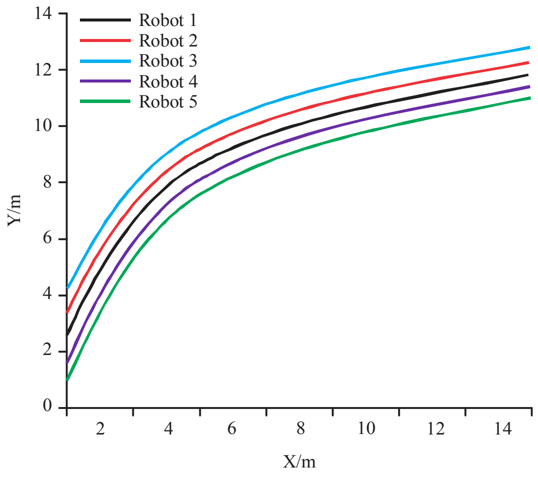

Fig. 5: Robots formation path, t = 300 sec

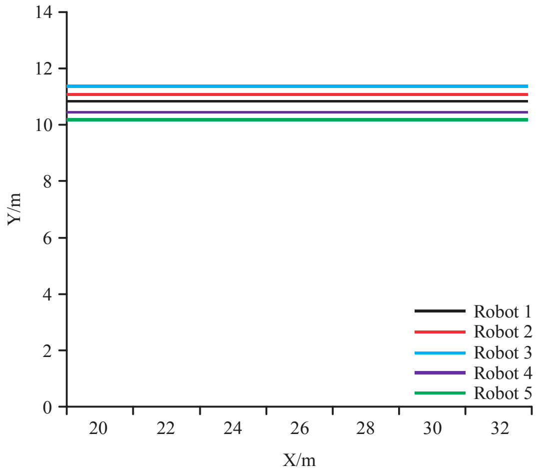

Fig. 6: Robots formation path, t = 600 sec

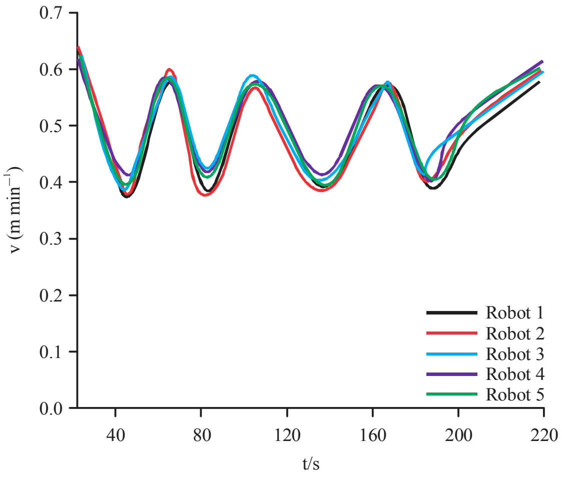

Fig. 7: Velocity control input

Table 1: Robot hierarchy parameter

Types	Level	No.	Controlled by upper robot number
Head robot		1	
Following robots	One	2	1
	Two	3	1,2
	Three	4	1,2,3
		5	1,2,3

Table 2: Desired distance d_{ij} (m)

Robots	1	2	3
2	1.0	0.0	1.0
3	1.0	1.0	0.0
4	2.0	1.0	1.732
5	2.0	1.732	1.0

DISCUSSION

At present, multiple robots autonomous formation control based on pigeon behavior is a new method. Many multiple robots autonomous formation adopt other ways. For example, Takahashi *et al.*[14] used the "Leader-following" strategy to control multiple mobile robots in formation. In this study, a performance index that showed mobile robot ability was quantified. Specifically, maximum acceleration and maximum velocity of a robot were defined by maximum admissible rotation and maximum continuous torque of a motor. Third, a compliance controller using a virtual repulsion was suggested, so that each robot could avoid collision. Dorfler and Francis[15] proposed a distributed control law based on potential functions. Zuo *et al.*[16] first investigated the static coverage problem of two-agent systems in flowing environment and presented an example by extending the two-agent systems into the general case. In addition, Gaussian estimation was introduced to predict the value of the sensory function through the sampled measurements. Peng *et al.*[17] adopted consensus-based approach to solve distributed formation control problem for multiple non-holonomic mobile robots. And some other proposed methods are applied into multiple robots form autonomous formation[18-21].

Comparing the simulation results with the theoretical analysis, this new model can effectively help multiple robots form autonomous formation and also keep the structure.

In summary, it is conducted that a short collection of important points cover the new findings:

- Using our new pigeon behavior model, cooperation and coordination between robots can help them better complete a large number of works that cannot be done by single robot. They improve their work ability through resource sharing and cooperation, which effectively makes up the shortcomings of original multiple robots
- Multi-robot system with new model has parallelism, which can use the distributed way to complete the task, which saves the completion time and improves the completion speed of system
- Multi-robot system has the redundancy and parallelism, which can improve the fault tolerance and robustness of the whole system, etc.

CONCLUSION

In this study, in order to solve the problems in multiple robots autonomous formation control, it studies the pigeon behavior in the nature. And the pigeon flocks model is applied into robots autonomous formation based on its special hierarchy behavior. It makes model from two aspects: One is that directed graph is used to describe topological structure and make model for hierarchy in pigeons; the other is that it makes model for leadership function of upper pigeons based on Vicsek model and A/R model. According to the the above two aspects, it designs the multiple robots autonomous formation control based on pigeon flocks. Finally, the experiments show that this new model can effectively help multiple robots form autonomous formation and also keep the structure. In the future, it will be introduce more intelligence algorithms to improve the multiple robots autonomous formation control.

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REFERENCES

1. Lu, Z., C. Xu, X. Zhao, L. Zhang, H. Wang and Q. Pan, 2013. Ultrasonic transmission testing of twin-robots coordinated control. Proceedings of the IEEE International Conference on Mechatronics and Automation, August 4-7, 2013, Takamatsu, pp: 1256-1260.
2. Ding, L., H. Gao, Z. Deng and Z. Liu, 2010. Slip-ratio-coordinated control of planetary exploration robots traversing over deformable rough terrain. Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems, October 18-22, 2010, Taipei, pp: 4958-4963.
3. USGSOSAT., 2011. Oil shale resources in the eocene green river formation, greater green river basin, Wyoming, Colorado and Utah. U.S. Geological Survey Oil Shale Assessment Team (USGSOSAT), Center for Integrated Data, Analytics Wisconsin Science Center.
4. Durham, J. and R. White, 2015. Collective resilience following mine clearance in Kurdish Iraq. Int. J. Disaster Resilience Built Environ., 6: 156-167.
5. Droge, G., 2015. Distributed virtual leader moving formation control using behavior-based MPC. Proceedings of the American Control Conference, July 1-3, 2015, Chicago, IL., pp: 2323-2328.
6. Askari, A., M. Mortazavi and H.A. Talebi, 2015. UAV formation control via the virtual structure approach. J. Aerospace Eng., Vol. 28. 10.1061/(ASCE)AS.1943-5525.0000351.
7. Ying, Z. and L. Xu, 2015. Leader-follower formation control and obstacle avoidance of multi-robot based on artificial potential field. Proceedings of the 27th Chinese Control and Decision Conference, May 23-25, 2015, Qingdao, pp: 4355-4360.
8. Lima, P.U., A. Ahmad, A. Dias, A.G.S. Conceicao and A.P. Moreira *et al.*, 2015. Formation control driven by cooperative object tracking. Robotics Autonomous Syst., 63: 68-79.
9. Sun, Z. and B.D. Anderson, 2015. Rigid formation control with prescribed orientation. Proceedings of the IEEE International Symposium on Intelligent Control, September 21-23, 2015, Sydney, NSW., pp: 639-645.
10. Morozova, N.S., 2015. Formation motion control for a multi-agent system simulating autonomous robots. Moscow Univ. Comput. Math. Cybernetics, 39: 175-183.
11. Beason, R.C. and W. Wiltschko, 2015. Cues indicating location in pigeon navigation. J. Compa. Physiol. A, 201: 961-967.
12. Whiten, A., 1972. Operant study of sun altitude and pigeon navigation. Nature, 237: 405-406.
13. Duan, H. and P. Qiao, 2014. Pigeon-inspired optimization: A new swarm intelligence optimizer for air robot path planning. Int. J. Intell. Comput. Cybernetics, 7: 24-37.

14. Takahashi, H., H. Nishi and K. Ohnishi, 2004. Autonomous decentralized control for formation of multiple mobile robots considering ability of robot. IEEE Trans. Ind. Electr., 51: 1272-1279.
15. Dorfler, F. and B. Francis, 2009. Formation control of autonomous robots based on cooperative behavior. Proceedings of the IEEE European Control Conference, August 23-26, 2009, Budapest, pp: 2432-2437.
16. Zuo, L., W. Yan, R. Cui and J. Gao, 2016. A coverage algorithm for multiple autonomous surface vehicles in flowing environments. Int. J. Control Automation Syst., 14: 540-548.
17. Peng, Z., G. Wen, A. Rahmani and Y. Yu, 2015. Distributed consensus-based formation control for multiple nonholonomic mobile robots with a specified reference trajectory. Int. J. Syst. Sci., 46: 1447-1457.
18. Aranda, M., G. Lopez-Nicolas, C. Sagues and Y. Mezouar, 2015. Formation control of mobile robots using multiple aerial cameras. IEEE Trans. Robotics, 31: 1064-1071.
19. Qian, X., A. De La Fortelle and F. Moutarde, 2016. A hierarchical model predictive control framework for on-road formation control of autonomous vehicles. Proceedings of the IEEE Intelligent Vehicle Symposium, June 2016, Goteborg, Sweden.
20. Reyes, L.A.V. and H.G. Tanner, 2015. Flocking, formation control and path following for a group of mobile robots. IEEE Trans. Control Syst. Technol., 23: 1268-1282.
21. Cai, X. and M. de Queiroz, 2015. Adaptive rigidity-based formation control for multirobotic vehicles with dynamics. IEEE Trans. Control Syst. Technol., 23: 389-396.