Improved Leader-Follower Method in Formation Transformation Based on Greedy Algorithm

Yan-Yu Duan(✉), Qing-Ge Gong, Zhen-Sheng Peng, Yun Wang, and Zhi-Qiang Gao

Department of Information Engineering, Engineering University of PAP, Xi'an, China
1530189605@qq.com

Abstract. A method based on the leader-follower method is proposed for formation transformation in large-scale mass incidents. The greedy algorithm is introduced to realize regional division and leader matching problem in target formation by constructing a distance matrix, and to calculate the distribution of followers. In order to solve the problem of path conflict without error feedback, collision detection and collision avoidance are proposed, which effectively avoids motion failure. Experiment of transforming the line formation into wedge-shaped formation is simulated, and the result shows that the proposed formation transform method is feasible and can effectively improve the efficiency of formation transformation.

Keywords: Computer application · Formation transformation · Follower-leader · Greedy algorithm · Collision avoidance

1 Introduction

Formation transformation is a vital task for emergency-dealing. Timely and effective formation transformation can not only enhance the resistance to external forces attack and improve the ability to maintain the robustness of the formation [1, 2], but also strengthen the deterrent force. The group formation control technology is widely applied for the transformation design, exercise and simulation verification in large-scale mass incidents, which can quickly and effectively show a better visual effect and improve the quality and efficiency of the design and training.

This paper studies on the group formation control based on the complex unknown environment. Group formation control refers to the process of multiple moving objects to maintain a certain predefined formation or transform into a new formation under the constraints of the environment and their own rules. Group formation control methods can be divided into four parts: the formation of the constraint shape, the layout of each object in the formation, the pairing among the objects in the formation transformation, and the collision detection and collision avoidance in the motion [3].

© Springer International Publishing AG 2018
L. Barolli et al. (eds.), *Advances in Internetworking, Data & Web Technologies*,
Lecture Notes on Data Engineering and Communications Technologies 6,
DOI 10.1007/978-3-319-59463-7_70

2 Greedy Algorithm Based on Leader-Follower Method

Combined with the leader and greedy algorithm [4, 5], in the moving process of the formation towards the target point, obstacle avoidance is achieved and the geometric pattern remains unchanged; the obstacle avoidance and formation maintenance can be carried out simultaneously or successively. The merits of the formation can be judged by its performance indicators [4], as follows:

(1) The path length ratio, that is, the ratio of the average length of the whole team's moving path to the shortest straight-line distance between the starting point and the target point; the smaller the value, the better the effect.
(2) The formation retention rate, the proportion of the members located in the desired position.
(3) The running time, the time to reach the target position as a whole.

2.1 Formation Maintenance Based on Leader-Follower Algorithm

The basic idea of leader-follower algorithm [1] for formation maintenance is that in a group formation of multiple moving objects, one or more are designated as leaders, the remaining objects as the followers of the leader, which follow the leader's position and direction at a certain distance, thus maintaining a variety of formations [6]. In the leader-follower control structure, the group formation structure can be divided into parallel structure and series structure, as shown in Fig. 1.

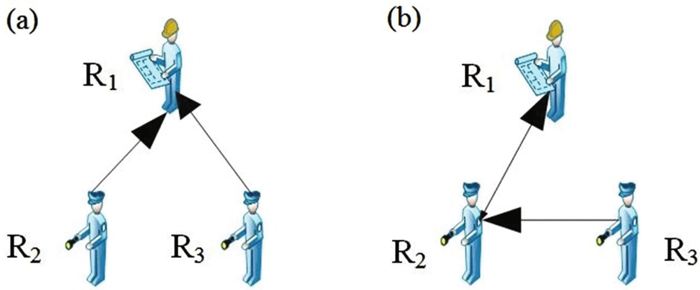

Fig. 1. Parallel structure (a) and series structure (b).

Leader is the core of the formation affecting the movement of the whole group, and the leader's state, speed, direction and other information are shared and visual for the followers. In series structure, each follower determines its position according to the $l-\varphi$ controller of the neighboring leader; in parallel structure, each follower's position is determined only by the $l-l$ controller of the only leader. Combined with LFS (Leader-to-Formation Stability) theory [3], the stability of two basic formation forms are analyzed and compared. It is concluded that the stability of parallel formation with single leader is higher than that of series formation. Since the formation transformation of troops involves in multiple leaders, this paper uses parallel structure to conduct the transformation.

Advantages of the leader-follower algorithm [7, 8] is that simply a given act or trajectory of the leader can control the subsequent behavior of the whole team, so the formation control problem can be simplified as an independent tracking problem, and each follower only needs to obtain the status information of the leader, which greatly simplifies the formation cooperation. The main drawback of this method is that there is no explicit formation feedback in the system. For example, if the leader moves too fast, the follower is likely to be lost. Another drawback is that if the leader were to fail, the whole formation would not be maintained. Therefore, the greedy algorithm is introduced to carry on the conditional feedback control method [7]. The positional relationship between the leaders and the followers is described as follows:

$$\begin{matrix} x_{Follower} = x_{Leader} + x_{Team} \\ y_{Follower} = y_{Leader} + y_{Team} \end{matrix}. \tag{1}$$

The desired position of each follower in the formation is derived according to the task, and combining with the environment information, the control variable is generated based on the control strategy, and the formation information is fed back to the leader. In the normal movement, the feedback information does not influence the leader's movement, and the follower adjusts its own speed to maintain the formation [9]. Only is a follower on the edge of the communication range, the leader would slow down to make the backward follower catch up.

The flow chart of the formation maintenance algorithm is shown in Fig. 2.

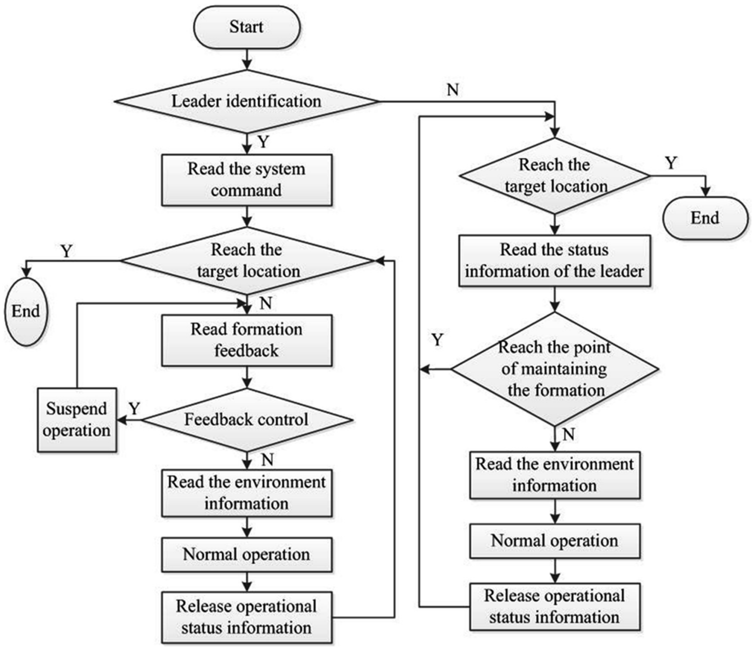

Fig. 2. The flow chart of the formation maintenance algorithm.

2.2 Greedy Algorithm

The greedy algorithm [4, 10] starts from a certain initial solution of the problem, and obtains the optimal choice in the current state through a series of greedy choices, and gradually approaches the given target and then gets the optimal value as fast as possible. The algorithm stops when a certain step in the algorithm can no longer proceed. The greedy algorithm adopts the method of constructing the optimal solution step by step. At each stage, a seemingly optimal decision is made (under certain criteria).

The solving steps of greedy algorithm are as followed:

Start from a certain initial solution of the problem;

While (a step forward towards a given target based on greedy strategy) do

Find a solution element of the feasible solution;

A feasible solution is obtained by the combination of all elements.

Based on the leader-follower algorithm, the region of the target formation is divided. In order to get the optimal position distribution of the followers in the formation [11], the greedy algorithm is introduced, based on which a distance matrix is constructed and the matching problem of each leader in the target formation is realized, and then the distribution of each member in the target formation is obtained according to the location of the leader.

3 Modeling and Simulation

In computer simulation theory, the position of each virtual member is determined by coordinates. In this study, the emergency site is simulated as a two-dimensional plane. Each point on the plane has one unique coordinate (x, y), and the drop point of each virtual member corresponds to one coordinate point on the plane. The position change of the member can be regarded as the change of the coordinate value, and the interval between the coordinate points indicates the distance between the members. When the formation needs to be transformed, the forward direction of each member can be calculated based on the source coordinate and target coordinate.

In this paper, the field where the emergency-dealing formation locates is a flat site, which can be regarded as a two-dimensional plane. The moving increments Δx and Δy in x and y coordinate directions represent the movement direction of the virtual members. According to the value of Δx and Δy continuously recorded with some certain frequency, the route of the virtual members can be obtained. With the route transformation algorithm, the whole transformation process can be simulated to visually show the detailed trajectory of each member's route transformation during the formation transformation.

Because of the reality demands of emergency-dealing, each team member must remain in the group aggregation after the formation transformation. Therefore, this paper divides the transformed formation into polygon areas according to the number of the leaders. Firstly, the location nearest to the centroid of each region is taken as the target position of the leader; secondly, the leader is arranged to each region using the greedy algorithm; and then followers are matched to the leader by greedy algorithm so that location mapping is achieved; finally, the collision that may occur during the movement is detected and avoided.

3.1 Formation Control with Greedy Algorithm Based on Conditional Formation Feedback

In order to coordinate the obstacle avoidance and formation maintenance, when a member of the formation is in the state of obstacle avoidance, greedy algorithm is used so that other members can replace him to maintain normal operation. With a parallel structure, there is no relationship between followers while maintaining the formation. These features make the formation control framework greatly flexible. In the movement, if the obstacle avoidance path is relatively long, leading to the follower out of the leader's communication range, there will be a departure. Formation feedback is introduced to overcome this shortcoming, but causing obstruction in the whole movement. And when multiple followers mistakenly stuck in the obstacle avoidance state at the same time, the system will be locked as the leader formation feedback is stop. Therefore, conditional formation feedback [4] is introduced, as shown in Fig. 3.

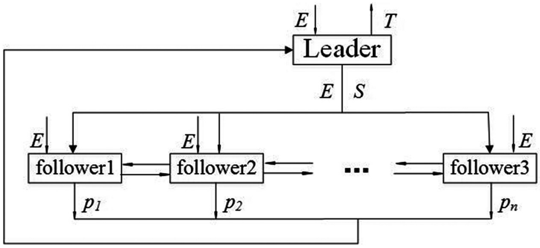

Fig. 3. The leader-follower control structure of the formation conditional feedback.

A two-dimensional plane is simulated, and n leaders are simulated as points on the plane. A matrix is introduced, representing the distance between the source position and the target position of each leader. So the problem of finding the shortest path will be transformed into a problem of finding the smallest number in a matrix of $n \times n$, which is noted as $L_{n \times n} = (a_{ij})$. Where, i indicates the nth leader in the source position; j indicates the position of the i-th leader in the target formation; a_{ij} represents the distance from the source position to the target position of the i-th leader. During the transformation, all the virtual members run reasonably so that the entire formation can be transformed into a certain target formation from an initial one. The positions of the virtual members are determined both in initial and target formation, and the movement routes of the members are uncertain. Assuming that the distance between the initial and target landing point of the virtual member is defined as a route, the shortest route priority algorithm is to find an ideal route that is the shortest one of all the routes without considering any conflict [12]. A virtual member's post move means running along the route from the initial landing point to the virtual landing point of the target formation. Based on the distance from the source position to the target position, an distance matrix of $n \times n$

$$\begin{pmatrix} 26 & 15 & 12 & 11 & \cdots \\ 37 & 20 & 14 & 21 & \cdots \\ 19 & 12 & 8 & 24 & \cdots \\ 9 & 13 & 11 & 23 & \cdots \\ \vdots & \vdots & \vdots & \vdots & \end{pmatrix} \rightarrow \begin{pmatrix} 26 & 15 & 11 & \cdots \\ 37 & 20 & 21 & \cdots \\ 9 & 13 & 23 & \cdots \\ \vdots & \vdots & \vdots & \end{pmatrix} \tag{2}$$

is obtained. The change in this distance matrix indicates that the shortest path is $a_{33} = 8$ according to greedy algorithm.

Combined with the conditional feedback mechanism, simulation is conducted using the greedy algorithm. To form a diamond-shaped formation as an example, the position code is as follows:

```
position_x = [leader_xleader_x-40leader_x-40leader_x-80];
position_y = [leader_yleader_y-10leader_y + 10leader_y].
```

First calculate the distance between the i-th follower and the leader, and then the distance between the i-th follower and each position of the target geometric formation, and finally find the nearest location from the i-th follower, which is the target point of the i-th follower in the diamond-shaped formation. Figure 4 shows the process of the formation movement simulation mentioned above.

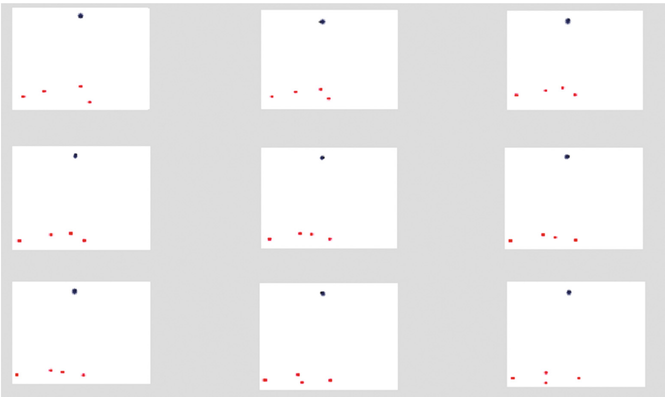

Fig. 4. Initial formation display process.

Figure 4 shows that the formation control with greedy algorithm based on conditional feedback can effectively maintain the formation in obstacle avoidance.

3.2 Collision Prediction

As mentioned above, the position of each member in the target formation is obtained with conditional feedback based on greedy algorithm. However, during the transformation of the entire formation, there will inevitably be a situation where two or more members being at one same position at a certain moment, which is called collision problem. If this problem is not dealt with, the entire formation will be stagnant [13]. Therefore, the collision prediction should be conducted throughout the transformation.

In this paper, x represents one emergency-dealing member, $L(x)$ represents the current position of x, $V(x)$ represents the speed of x, and $W(x)$ the width of the area (a fixed value in this paper). Assuming that two adjacent members are a and b, and $L_r = L(a) - L(b), V_r = V(a) - V(b)$, where L_r represents the relative position of a and b, V_r represents the relative velocity of a and b, a possible collision event between a and b satisfies:

$$L_r^2 + 2 \times L_r \times V_r \times t + V_r^2 \times t^2 = \left(W(a) + W(b) + \varepsilon^2\right) \tag{3}$$

where ε is the safe distance of a and b. If there is no solution or just one unique solution, then there is no predictive collision between a and b. If there are two solutions t_1 and $t_2 (t_1 < t_2)$, then there is a collision that will happen immediately (that is, need to avoid collision) if $t_2 < 0$; and if $t_1 \geq 0$, the collision will occur after t_1. The collision time can be denoted by t_p uniformly, then $L_a = L(a) + V(a) \times t_p$, $L_b = L(b) + V(a) \times t_p$, where L_a and L_b represents the position of a and b after the time of t_p respectively, and then:

(1) $(L_a - L_b) \times V(a) < 0$ represents rear collision,
(2) $(L_a - L_b) \times V(a) > 0$ and $V(a) \times V(b) < 0$ represent front collision,
(3) $(L_a - L_b) \times V(a) > 0$ and $V(a) \times V(b) \geq 0$ represent rear collision,
(4) $\|V(b)\| = 0$ represents static collision.

The above four types of collisions are proposed to design a local collision avoidance algorithm.

3.3 Collision Avoidance

The collision avoidance designed in this paper is mainly achieved by the speed change. Speed is mainly determined by magnitude and direction, so collision avoidance of two members can be realized by changing the direction, magnitude, or both at the same time. Direction change is divided into left and right; speed change is divided into acceleration and deceleration. Since the deceleration of a is equivalent to the acceleration of b, acceleration rules can be achieved through the deceleration rules. The geometrical explanations of the left, the right and the speed-shift avoidance are shown in Figs. 5, 6 and 7 respectively.

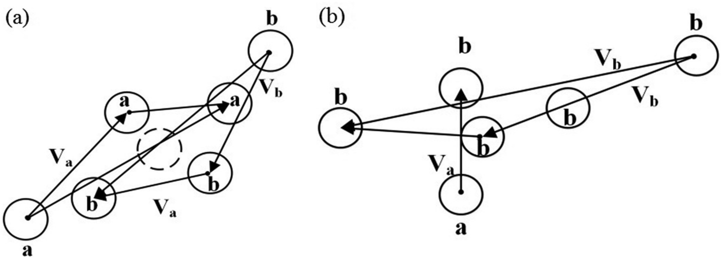

Fig. 5. Left avoidance: (a) front collision; (b) (static) collision.

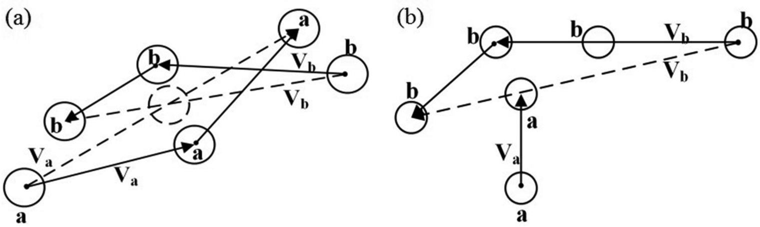

Fig. 6. Right avoidance: (a) front collision; (b) (static) collision.

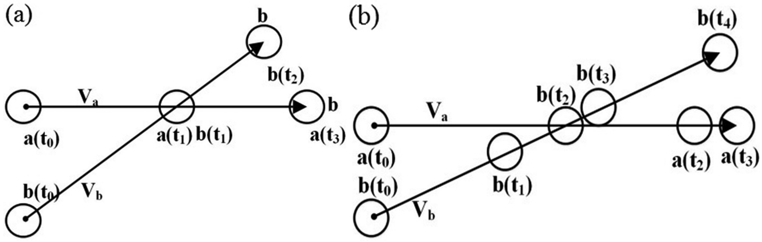

Fig. 7. Speed-shift avoidance: (a) collision at t_1 $(V_a < V_b)$; (b) a reaches the collision point far before b at the speed of $V_a (V_a > V_b)$.

4 Simulation Experiment and Result Analysis

In the process of dealing with emergencies, the formation is required to maintain a certain geometric shape according to the specific task requirements, and continue to transform in the development of the situation to better accomplish the task [9]. Typical basic simple formation includes line formation, diamond-shaped formation, wedge-shaped formation, the inner circle, the outer circle and so on [6]. In order to verify the feasibility of the proposed method, this paper simulates the transformation of the line formation into the wedge formation, and the transformation effect is shown in Fig. 8.

This experiment is implemented in the Matlab environment. Firstly, 100 source formation positions are given and divided into 10 groups, and each point located in the

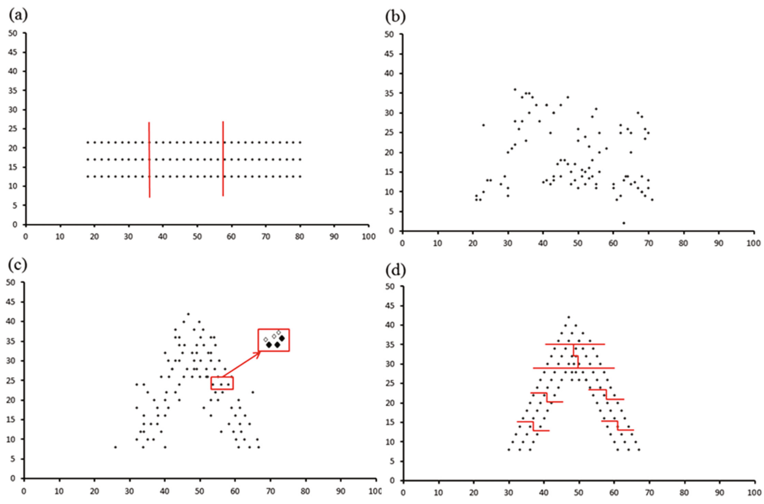

Fig. 8. The diagram of the transformation effect of the line formation to the wedge formation: (a) original formation (line); (b) transformation 1 (c) transformation 2 (d) target formation (wedge-shaped).

centroid position is the leader. And then, 100 target formation positions are given and divided into 10 regions by polygon, and the point closest to the center of each region is the target position of the leader. According to the greedy algorithm, the mapping coordinates of the leader of the initial formation to the target formation are obtained. Finally, the mapping coordinate of each team member is obtained by using the greedy algorithm. In the movement, collision avoidance is achieved according to the obstacle avoidance rule mentioned above (as shown in transformation 2).

Figure 8 shows that the formation begins to aggregate at transformation 1, that is to say, the leader groups emerge; and the target formation starts to emerge at formation 2. During the whole process of the transformation, there is always a gap between the points, and no collision occurs. From the perspective of the transformation, the path obtained by greedy algorithm is feasible, yet not optimal.

5 Conclusion

Based on the leader-follower algorithm, for formation transformation in emergencies,, this paper tries to get the position mapping of the team members from the original formation to the target formation by greedy algorithm. And in the process of path selection, collision detection and collision avoidance are realized by geometric constraint mechanism. The transformation of the line formation to the wedge-shaped formation is simulated by Matlab. The simulation results indicate that the decision-making process is distributed at each level, and the introduction of the greedy algorithm can reduce the information transmission, shorten the state probability of decision-making time, and greatly enhance decision-making adaptability under the dynamic uncertain condition. The method proposed in this paper is feasible for the formation transformation, and can improve the efficiency of formation design and exercise in emergencies. In the future, the formation transformation of small-scale units will be studied.

Acknowledgments. This work was supported by Shanxi Provincial Natural Science Foundation of China Youth (2015JQ6224) Colored Nodes and Network Complexity Measure Research.

References

1. Zhang, Z.Y., Zhang, R.B., Xin, L.: Hybrid formation control of multi-robot. J. Univ. Posts Telecommun. 38–41 (2008)
2. Wen, R., Li, D.W., Luan, X.F.: Path planning of robot based on ant colony algorithm. Comput. Digit. Eng. 20–22 (2012)
3. Consolini, L., Morbidi, F., Prattichizzo, D.: Leader–follower formation control of nonholonomic mobile robots with input constraints. Automatica **44**(5), 1343–1349 (2008)
4. Singh, J.A.: A greedy algorithm for task scheduling and resource allocation problems in cloud computing. Int. J. Res. Dev. Technol. Manag. Sci. Kailash **21**(1), 1–17 (2014)
5. Giryes, R.: A greedy algorithm for the analysis transform domain. Neurocomputing **173**, 278–289 (2016)
6. Lin, J.L., Hwang, K.S., Wang, Y.L.A.: Simple scheme for formation control based on weighted behavior learning. IEEE Trans. Neural Netw. Learn. Syst. **25**(6), 1033–1044 (2014)
7. Sharma, S., Jerripothula, S., Mackey, S.: Immersive virtual reality environment of a subway evacuation on a cloud for disaster preparedness and response training. In: 2014 IEEE Symposium on Computational Intelligence for Human-like Intelligence (CIHLI), pp. 1–6. IEEE (2014)
8. Wang, B., Wang, J., Zhang, B.: Leader-follower consensus for multi-agent systems with three-layer network framework and dynamic interaction jointly connected topology. Neurocomputing **207**, 231–239 (2016)
9. Peng, Z., Wen, G., Rahmani, A.: Leader-follower formation control of nonholonomic mobile robots based on a bioinspired neurodynamic based approach. Rob. Auton. Syst. **61**(9), 988–996 (2013)
10. Pan, Q.K., Ruiz, R.: An effective iterated greedy algorithm for the mixed no-idle permutation flowshop scheduling problem. Omega **44**, 41–50 (2014)
11. Ou, M., Du, H., Li, S.: Finite-time formation control of multiple nonholonomic mobile robots. Int. J. Robust Nonlinear Control **24**(1), 140–165 (2014)
12. Ma, T., Tang, B., Wang, Y.: The simulated greedy algorithm for several submodular matroid secretary problems. Theory Comput. Syst. **58**(4), 681–706 (2016)
13. Niewiadomska-Szynkiewicz, S.: Simulation-based design of self-organising and cooperative networks. Int. J. Space-Based Situated Comput. doi:10.1504/IJSSC.2011.039108