Simulation Research on adaptive Formation Capturing Algorithm for Multi-robot

Yong Zhang [a], Shouyuan Chen [b], Zengzhen Shao [c]

School of Information Science and Engineering, Shandong Normal University, Jinan 250300, China;

[a]734631225@qq.com, [b]shouyuanchen@163.com,[c]939996905@qq.com

Abstract

In this paper, an adaptive rigid formation algorithm is proposed to solve the problem of hatching deadlock caused by the fixation and stability of traditional rigid structures in multi-robot hunt problem. The leader sends the number and location information of the target to the follower, and takes a single round-off strategy for multiple targets, which forms a suitable formation to complete the round-the-clock by using the environmental conditions, such as the boundary, to virtual the location where the capture cannot reach. In this paper, we construct the formation center controller so that the center can infinitely approach the target. Additionally, it combines the formation controller to dynamically adjust the formation. Combined with the proposed adaptive rigid formation algorithm, we develop a platform based on Netlogo and we have done experiments to validate it. Meanwhile, we make a comparison between the traditional rigid formation and adaptive rigid formation algorithm, the result shows that the adaptive rigid algorithm can avoid the hunt of the target successfully, and the time index and energy index used are better than the traditional rigid structure method, thus proving that the adaptive formation strategy is effective.

Keywords

Multi-robot; Adaptive rigid structure; Collaboration capturing; Simulation.

1. Introduction

Multi-robot system (MRS) has emerged as a product of cheap sensing and actuating capabilities of small, and moderately sophisticated robots and advancements in distributed problem-solving. MRS used to describe and solve large classes of problems such as searching, capturing and exploration. MRS usually have mobile and autonomous participating robots, performing the task cooperatively. Formation control is one of the necessary and important problems in the research field on the MRS[1].Formation control of autonomous robots is desired based on the formation in the nature, for example schools of fishes, flocks of bees, swarm of ants ,etc., and guaranteed that members in the formation have to move together under the velocity matching without collisions among them[2]. Modeling and simulation are essential tools in many areas of computer science, including MRS.

There are many methods solving the formation problems, such as the control algorithm with the idea of rigid structure[3], by which the relative position between the robots is difficult to change. Although this method can ensure the stability of the formation, it cannot be changed flexibly and effectively in some situations so that the hunter fails to capture the target. Another method is that the motion of all robots are driven by a given dynamic framework[4], the result of this approach has shown that robots are able to adjust the formation by rotating and scaling when moving together. It is difficult for the robot to maintain a stable structure with this method.

The study of multi-robot formation is based on rigid structures. Fang Baofu, Pan Qishu, who researched on the two-dimensional plane robots with n hunters and one target, studied the constraints of successful capture, and pointed out a problem of blind angle[5]. Some researchers have studied the tracking problem of multi-robot, and realized the rigid tracking formation of multi-robot with rigid algorithm and leader-follower coordination strategy[6,7,8]. Duan Min designs the mean estimation controller based on the neighbor information and studies the surrounding control algorithm for the different formation of the single-objective multi-robot system[9]. Now the problem in the current studies can be summarized as follows: (1) Rigid structure is easy to achieve local optimum, and it needs maintain the optimal formation by giving up some index[10,11]. (2) Multi-robot system focuses on the pursuit of the overall consistency thus ignoring the flexibility of the formation. In some cases, there is a problem of blind angle [12]. (3) Current studies are mainly based on single-target hunt that cannot form an effective escape alliance[13].

This paper considers a new method for the formation control of autonomous robots, which adjust rigid formation dynamically to round up the targets' escape alliance. The method combines the rigid structure with the adaptive idea to construct an adaptive rigid formation algorithm. In this paper, we improve the capture of simulation platform based on Netlogo to validate the algorithm. Result shows that the time and energy index of the adaptive rigid capture algorithm are superior to that of the traditional rigid formation algorithm in the form of targets' escape alliance.

2. Controller design

2.1 Center controller design

There are n robots, and the following equation of state is satisfied[14]: $\dot{y}_i(t) = f_1[u_i(t)]$, where $u_i(t)$ represents the input pose of the robot-i, $\dot{y}_i(t)$ is the output position state of the robot-i, i = 1, 2, 3, ... n. If hunter wants to successfully arrest the target in the time of period T, it needs to meet the following condition: $\lim_{x\to T}\left|l_{avg}(t) - l_{tar}(t)\right| = 0$, where $l_{tar}(t)$ is the pose information of the target, $l_{avg}(t)$ is the average formation center of the hunter, and $l_{avg}(t) = \frac{1}{n}\sum_{k=1}^{n} l_k(t)$. The formation center needs to converge to the target position within a finite time T to infinitely access the target. So we design the center controller as is shown below: $f_1 = U_{avg}(t) + [U_{tar}(t+\Delta t) - U_{tar}(t)]$, $U_{tar}(t+\Delta t) - U_{tar}(t)$ represents the target pose changes that occur within time Δt.

2.2 Formation controller design

In this paper, we use the circular formation (shown in Figure 1) to capture the target, and define the state equation with polar coordinates with the equation $\dot{\rho_i}(t) = \mu_i(t)$, $\dot{\theta_i}(t) = u_i(t)$,where $\dot{\rho_i}(t)$ represents the polar radius of the hunter-i with the Target as the origin of the coordinates, $\dot{\theta_i}(t)$ represents the polar angle of the hunter-i with the Target as the origin of the coordinates, and i=1,2,3...n. We can get the formula as follows:

$y_i(t) = l_{tar}(t) + \left[\rho_i(t)\cos(\theta_i(t)), \rho_i(t)\sin(\theta_i(t))\right]^T$,and $l_{tar}(t)$is the target position information.

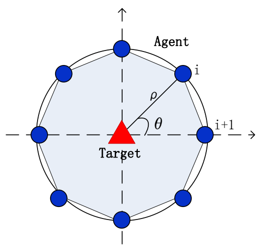


Fig.1 Surround formation figure (n=8)

Based on the above analysis, formation control can be expressed: $\lim_{x\to T}[|y_i(t) - l_{tar}(t)| - k\rho_i(t)] = 0$, $\lim_{x\to T}[\theta_i(t) - \theta_{i+1}(t) - \partial] = 0$. $y_i(t) - l_{tar}(t)$ represents the distance between the hunter and the target, $k\rho_i(t)$ is the radius of the formation, k is the variable formation radius factor. The formula: $\theta_i(t) - \theta_{i+1}(t) - \partial$ is the angle difference between the hunter-i and the hunter-i+1 and the preset formation angle, $0^\circ \le \partial \le 180^\circ$. When the difference tends to zero within the period T, the hunter can be evenly distributed to the circle with the target as the center. So we design the formation controller as follows:

$$f_2 = \theta_i(t) + \Delta\theta$$

$$\Delta\theta = \partial - [\theta_i(t) - \theta_{i+1}(t)]$$
$$f_3(t) = y_i(t) + \Delta\rho_i$$
$$\Delta\rho_i = \rho_i - [y_i(t) - l_{tar}(t)]$$

$f_2(t)$ is the angle controller in the formation control. When the angle is shifted by the hunter-i, it adjusts the angle according to the interval angle between the formation preset angle ∂ and the hunter-i and its clockwise hunter i + 1 (see Fig.2). $f_3(t)$ is the radius of controller. As the distance between the hunter-i and the target changes, deviation of the formation preset radius ρ changes by Δρ, and hunter-i choose the best position by eliminating the radius offset(see Fig.3).

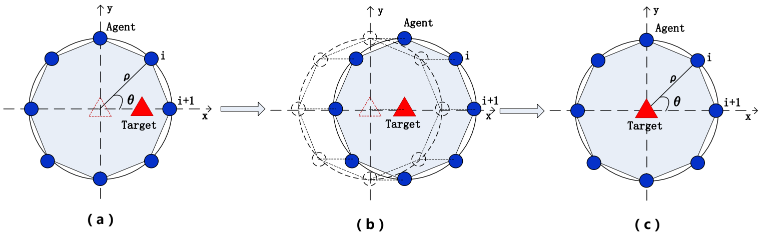


Fig.2 Formation center figure

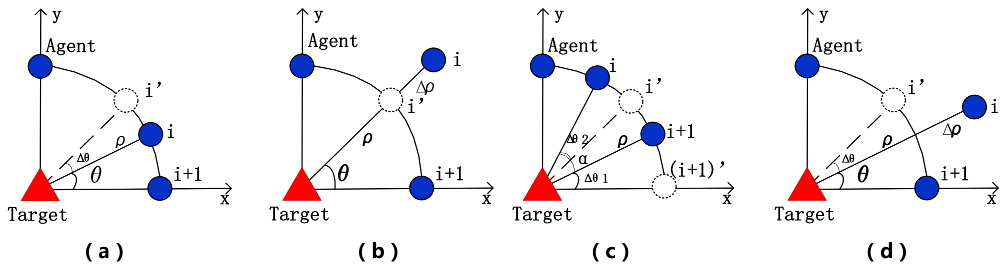


Fig.3 Formation control figure

3. Adaptive rigid structural formation algorithm

Aiming at solving the blind angle problem of the traditional rigid structure formation, we propose an adaptive rigid structure algorithm, which is based on the location of the target and imitates a circle formation. The algorithm can use the boundary and environmental conditions to capture the target in the formation center position, thus avoiding blind angle. The algorithm consists of patrol action, isolation action, formation and predict action. In the patrol action, the system marks the hunter who first find the target as Leader (hereinafter referred to as L), L will communicate with the remaining Followers (hereinafter referred to as F). If F finds multiple targets, they will separate from each other and follow the single target with the isolation action. In a platform with boundary, the target location is defined as three categories: Center, Border, Corner, and the minimum number of hunters are 8,5,3 respectively.

3.1 Portal action

At the beginning of the capture, the position of each robot is randomly distributed, and the hunter cannot obtain the position information of the target in advance. At this time, each hunter performs a patrol action. When the distance d_i of the hunter-i (i = 1,2 ..., n) and the target is greater than the detection radius r, the hunter-i is free to walk. To increase the patrol range and compress the moving radius of the target, hunter-1 needn't patrol as the original direction if it meets hunter-2. When the distance d_i of the hunter-i (i = 1,2 ... n) is smaller than its detection radius r, the hunter-i finds and locks the target, and then sends the target pose information to the other hunters to request the formation. If there are other hunters in the communication range, the formation action is executed, or the formation information will be sent again.

3.2 Isolation action

After discovering the target, L determine the number of targets and send target's information to F. If there is only one target, then continue to capture; if there are multiple targets, then L' appears, and so on, hunt the target separately. Taking into account the target anti-encirclement strategy, there will be a goal to run away separately or escape together, for the latter, can be regarded as a single target to hunt.

3.3 Formation action

L sends the target position and pose information to the F, a hunter in L's communication range, after hunting the target :① if F has not found the target, it should be directed by the information sent by L. ② If F finds the target, it estimates the optimal formation position, and compares it with the location information sent by L, and the smaller distance is the optimal position. If it has been occupied, then select the suboptimal position. According to the location of the target, L determines the minimum number of F and sends the information of pose to the F.

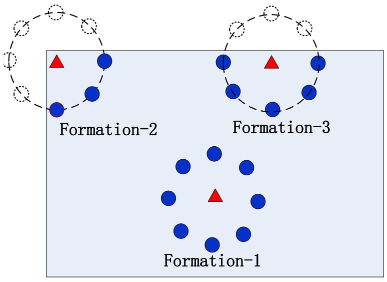


Fig.4 Target location

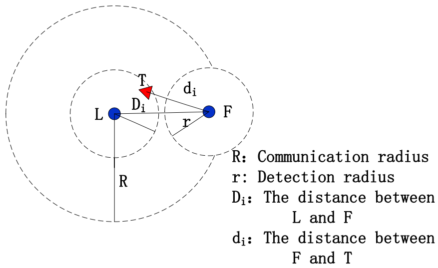


Fig.5 Leader-Follower

As is shown in Fig.4, the red triangle is the target, and the solid circle is the hunter and the dotted circle is the virtual position. When the target is located in the middle of the platform, it can form Formation-1; when the target is at the corner or border, L calculates the virtual circular formation and will send the expected pose to F, as is shown in Formation-2 and Formation-3. In a Leader-Follower module(see Fig.5), the hunter-i, within the scope of the leader's communication, can receive the information sent by L in the case of D_i<R. The target is outside the detection range of the F and is required to move according to the L's command in the case of D_i> r.

3.4 Predictive action

In the process of formation, the information received from F may be erroneous or loss of timeliness. At this point , F needs to predict the next moving trajectory of the target according to the received and registered pose information. F also needs to determine the optimal position to intercept the target combining with their own location.

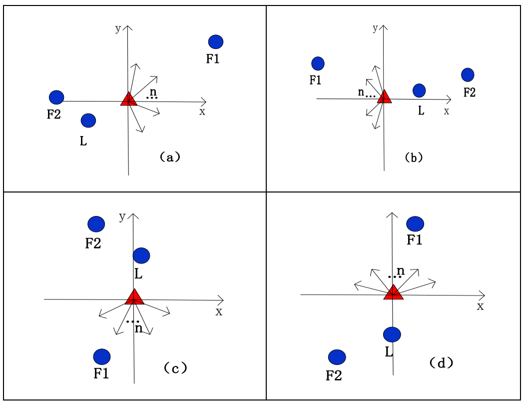


Fig.6 Predictive action figure

There are n possible directions for the target in Fig.6(a). We assume that the target moves to the right side of the Y-axis and the target lateral displacement points to the positive direction of the X-axis. The prediction mechanism is designed as follows: L sends the target information to F1 and F2 , and

F1 have more advantages than F2 with the target moving to it. Therefore, F1 predicts target's possible direction and speed of moving according to the continuous received target pose information to intercept, and F2 continue to chase. (b) (c) (d) also like above.

In summary, the adaptive rigid structure algorithm is as follows:

Step1: Portal action.

Step2: *L* determines the location of the target, and calculates the smallest number of hunters.

Step3 is performed if there are other hunters in the *L*'s communication range R (R> = 2r).

Otherwise, Step4 is executed.

Step3: Determine the number of targets. If there are two targets,Step5 is executed. If there is single

target, Step6 is executed.

Step4: *L* doesn't send the target information until *F* receives and responds.

Step5: Portal action.

Stpe6: If *F* does not find the target, execute Step7; otherwise execute Step8.

Step7: *F* performs a prediction operation based on the target information transmitted by *L*, and

moves to the instruction position.

Step8: *F* virtualizes and calculates the formation position based on the target information captured

by itself, combing the central controller with the formation controller.

Step9: The target stops moving, otherwise execute Step8.

4. Experiment analysis

In this paper, Netlogo is used to design the robot simulation platform. The adaptive rigid formation algorithm is compared with the traditional rigid structure in the same environment, and the effect of the two formation algorithms is expressed intuitively. The hunt time and energy dissipation index is compared .

4.1 Experimental data description

Tab. 1 Data description

Data description					
Hunter	8	**Detection radius**	38	**Speed**	V_H
Target	1	**Detection radius**	33	**Speed**	V_T
Platform size	600*280	**Robot size**	10	**Energy**	100

4.2 Simulation results and analysis

As shown in Figure 7 (a), hunters who doesn't find the target were patrolling. Fig.7(b) shows C1 receives the information sent by L and combines with the predicted action to guess the target's location. Then C1 moves to target to intercept. Hunter 2, 3 don't trigger the predictive action, and patrol. As shown in Fig. 7 (c), hunters find two targets, and separate action after L's command. L ' forms a new league of hunt. Fig. 7 (d) shows each hunter, according to the information sent by L and combined with the predictive action, has arrived at the formation location to join in the formation.

Fig. 7 (e) suggests when the target is on the border, five hunters are required to block the encirclement in the target escape direction, and the remaining hunters assist in hunting or continuing patrol. Fig. 7 (F) shows when the target at the corner, L, using adaptive rigid structure formation algorithm and predictive action, send the formation of change instructions to command C1、C2 to blocking target.

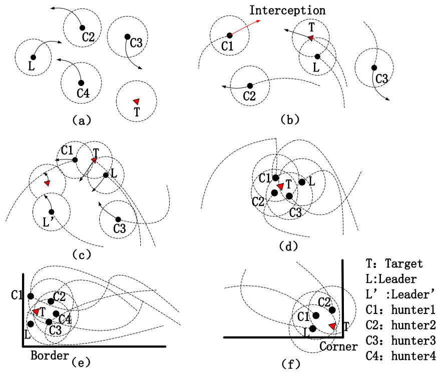


Fig.7Adaptive formation chase simulation results

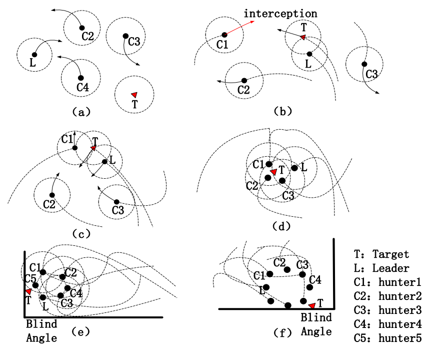
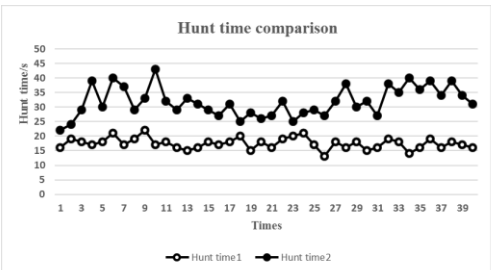


Fig.8Rigidstructure formation chase simulation

The method proposed in this paper is compared with the rigid structure control algorithm [15]. As shown in Fig. 8, (a) - (e) is similar to Fig. 7, we don't introduce again. Fig. 8 (e) shows that target is at the border, and the hunters form a stable rigid structure. There is a "force between the role", so it is difficult to flexibly adjust the formation, resulting in blind angle. Fig. 8 (f) indicates that the rigid structure leads to the blind angle and the target cannot be encircled at the formation center.

The simulation results are as follows:



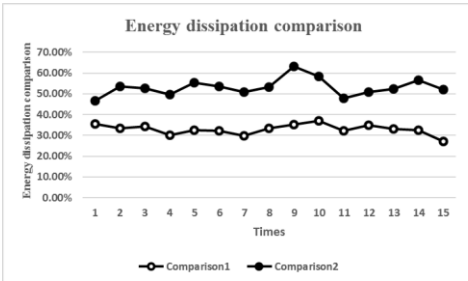


Fig.9 Hunter time comparison Fig.10 Capture for energy dissipation comparison

Fig. 9 suggests the results of 40 times experiments, the hollow circle represents the adaptive algorithm, and the solid dot represents the rigid formation algorithm. Time used in adaptive algorithm is shorter and more stable compared with rigid algorithm. Fig.10 shows the energy dissipation comparison result of 15 times. Specifically, hollow circle is energy dissipation of adaptive algorithm, which is stable with a rate of 30-40% and is lower in general level than that of rigid algorithm described with solid black point.

5. Conclusion

To solve the problem that the rigid structure can not be flexible to adjust the formation and that of existence of blind angle in the multi-robot fleeing, we propose adaptive rigid structure formation algorithm, that is to say, inside of the formation uses relative position to build rigid structure and adjust dynamically, thus circling the target in the center. In this paper, we first construct the formation center controller, and control the formation center to approach the target gradually. Secondly, we use adaptive rigid structural formation idea to design formation controller, and use it to control formation and make dynamic adjustment. Besides, we design pursuit of simulation platform based on Netlogo and validate the algorithm with many times of experiments. Time and energy dissipation are set as evaluation criteria in the experiment, and the result shows that time is shorter and the energy dissipation is relatively stable used by adaptive algorithm than rigid algorithm. To conclude above, the adaptive rigid formation algorithm proposed in this paper can effectively avoid the dead angle problem in the capture process.

The shortcoming of this paper is considering only a single intelligent goal, not joining the multi-objective alliance mechanism and not displaying the intelligence of the capture-system absolutely. In the future, we will research the pursuing problem by increasing the intelligence of targets, constructing the alliance between targets, using "game theory" and adaptive formation.

Acknowledgements

Thanks to the “ China Postdoctoral Science Foundation (No. 2016M592697)” and“ the Shandong Provincial Key Research and Development Program (No. 2014GGH201022)”.

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