PSO based Multi-robot Formation Control

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Abstract. Aiming at the environment that contains dynamic obstacles, a new multi-robot formation control method is proposed. Leader-Following method is combined with artificial potential field method to solve the poor adaptability of formation. Meanwhile, the robots' relevant parameters are optimized online by particle swarm optimization (PSO) algorithm. The simulation results show that the proposed method is effective and can solve the task of multi-robot formation control in a fantastic way.

Introduction

Multi-Robot Formation Control is a kind of control technology that all robots could reach a certain destination and maintain a fixed formation as well as adapt to the environment [1]. Currently, there are many multi-robot formation control algorithms, such as Behavior-based Control Method [2], Leader-Follower Algorithm [3, 4] and Artificial Potential Field [5]. The above-mentioned methods could well solve the multi-robot formation control problems, but their noticeable disadvantages cannot be overlooked: the Behavior-based Control Method could not analyze the control behavior well which makes it difficult to ensure the stability of formation; the Leader-Follower Algorithm lacks a formation feedback and its capabilities depends excessively on the Leader robot and the Artificial Potential Field could not get global optimum in general. In addition, many scholars focus on the simple conditions that contain static obstacles barely. It's important to research the multi-robot formation control in complex conditions.

In this paper, a new multi-robot formation control based on PSO [6] algorithm is proposed. The structure of this paper is organized as follows: In Section 2, hybrid multi-robot formation control is introduced; PSO based multi-robot formation control is discussed in Section 3; and in Section 4 simulation results are given. In Section 5, conclusions are brought forward.

Hybrid Multi-Robot Formation Control

Leader-Following Algorithm. The Leader-Following is a multi-robot formation control algorithm that chooses a leader in the formation of multi-robot. In this paper, the robot that has the shortest horizontal distance with the target point is leader, and the others are followers. In the process of movement, the followers control their behaviors by the necessary information that they get from the leader [7]. Therefore, the movement of formation is determined entirely by the behavior of leader. The system model is shown in the Fig. 1.

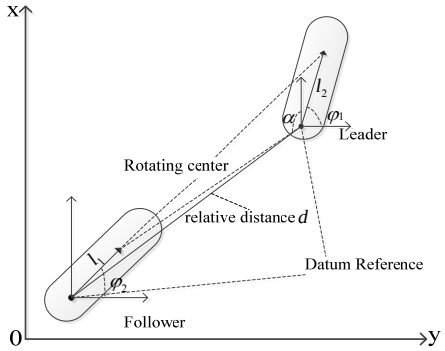


Fig.1 Leader-Following Model

Assuming that the relative distance between the leader and follower is d and the relative angle of them is δ [7]. The coordinates of the reference points are (x_i, y_i, φ_i, v_i, w_i) [8], where x_i and y_i denote the coordinates of the ith robot, v_i and w_i represent the corresponding linear velocity and the angular velocity, respectively. Then the coordinate of the rotating center can be described as

$$\begin{cases} r_{x_i} = x_i + l_i \sin\varphi_i \\ r_{y_i} = y_i + l_i \cos\varphi_i \end{cases}, \tag{1}$$

where i=1, 2. The relative distance is represented as follows

$$d = \sqrt{\left(r_{x_1} - r_{x_2}\right)^2 + \left(r_{y_1} - r_{y_2}\right)^2}. \tag{2}$$

According to Fig. 1, the followers' model can be described as

$$\begin{cases} \dot{d} = v_2\cos\phi - l_2 w_2 \sin\phi - v_1\cos\delta + l_2 w_2 \sin\delta \\ \dot{\delta} = \dfrac{1}{d}\left(v_1\sin\delta - v_2\sin\phi - l_2 w_2\cos\phi + l_1 w_1\cos\delta - d w_1\right) \end{cases}, \tag{3}$$

where $\begin{cases} \delta = a - \varphi_1 \\ \phi = \delta + \varphi_1 - \varphi_2 \\ l_1 = l_2 \end{cases}$.

According to the formulas which expressed before, the control variable of following robots can be given by

$$\begin{cases} w_2 = \dfrac{\cos\phi}{l_1}\left[a_2 d\left(\delta_d - \delta\right) - v_1\sin\delta - l_1 w_1\cos\delta + d w_1 + \vartheta\sin\phi\right] \\ v_2 = \vartheta + l_1 w_2 \tan\phi \end{cases}, \tag{4}$$

where a_1, a_2 are the proportional coefficients, $\vartheta = \dfrac{v_1\cos\delta}{\cos\phi} - \dfrac{l_1 w_1 \sin\delta}{\cos\phi} + \dfrac{a_1(d_d - d)}{\cos\phi}$.

According to the above variables, the following robot could control the linear velocity v_i and angular velocity w_i by itself. Hence, the relative position between the leader and following robots can be kept to an acceptable scale in the whole process of formation. However, the Leader-Following algorithm has no information feedback. Once the leader breaks the ranks or loses data, the whole formation of robots would be broken.

Artificial Potential Field. The basic idea of artificial potential field is introducing fictitious magnetic field artificially. Robots move forward under the effect of two forces (attraction and repulsion forces) [9]. Considering the attraction forces, the distance of two points is used to indicate. The repulsion forces were defined as

$$\mathrm{F} = \begin{cases} (lt - l)/(lt - lx) & lx \le l \le lt \\ D & l \le lx \end{cases}, \tag{5}$$

where l denotes the distance between the robot and obstacle, lt is the detective distance of sensors, lx is the limited distance and D is a constant, respectively.

Mixed Formation. The artificial potential field method is easy to be implemented. However, it usually encounters a local optimum when the distances between the target point and obstacles stay in a small scale. Hence, to address the problems mentioned above, an algorithm combined improved artificial potential field with leader-following is proposed in this paper, and a new formation of hybrid multi-robot is also established.

First of all, the speed of followers in leader-following will change by some rules. For example, the follower's speed will accelerate when it meet an obstacle or corner. In addition, some virtual leaders are set, current leader will be replaced by a virtual leader when current leader meets some problems. Second, the function of potential field in Artificial Potential Field was adjusted. Last but not least, considering the difficult of parameters' set and the uncertainty of disturbances in reality, the robots' relevant parameters are optimized online by PSO algorithm.

PSO based Multi-Robot Formation Control in Complex Environment

PSO based optimization the parameter of formation control. 1) PSO algorithm: Particle swarm optimization (PSO), a new evolutionary computing method, was developed by Kennedy and Eberhart in 1995 through the simulation of simplified social models of bird flocks [10].

In traditional PSO, each individual is regarded as a particle, which moves with an adaptable velocity in the search space [11]. Each iteration particle updates itself according to individual extremum (the optimal result of particle) pb and population extremum (the optimal result of particle swarm) gb each time. Assume that k denotes the particle number of iterations, $p(k)$ and $v(k)$ is the kth position and velocity of particle, then the particles are manipulated according to the following equation

$$\begin{cases} v(k+1) = w \cdot v(k) + K_1 \cdot l_1 \cdot \left[pb - p(k) \right] + K_2 \cdot l_2 \cdot \left[gb - p(k) \right] \\ p(k+1) = p(k) + v(k+1) \end{cases}. \tag{6}$$

where w, K_1 and K_2 stand for the inertia weight, acceleration coefficients, respectively. l_1 and l_2 are rand number between $(0,1)$. Since the ability of PSO depends greatly on the fitness function, in this paper, we select the fitness function as

$$fitness = l_{ddn} + l_{rrn} + l_{ron}. \tag{7}$$

where l_{ddn}, l_{rrn}, l_{ron} denote the steps of robots, the collision number among robots and the collision number between robots and obstacles, respectively.

2) PSO Based Multi-robot Formation Control Flow: The PSO algorithm was introduced in the complex multi-robot formation control to get the optimal velocity and position parameter of robots. The main steps are:

Step1: Initialize the system state and the parameters of PSO.

Step2: According to the fitness function, evaluate current particle's fitness value.

Step3: Update the particle position and velocity on the basis of (7).

Step4: Move horizon to the next sample time, and go back to step2 for the next iteration until whole control process is over.

The proposed hybrid multi-robot formation control. The Leader-Following method is combined with artificial potential field method and we introduced PSO algorithm to optimize the robots' relevant parameters online and the method of hybrid multi-robot formation control flow is depicted in Fig. 2.

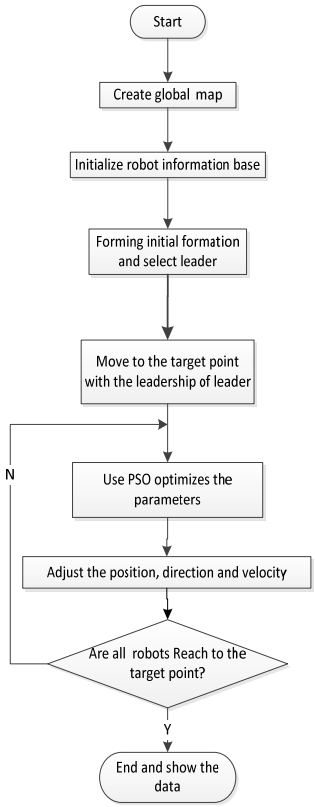
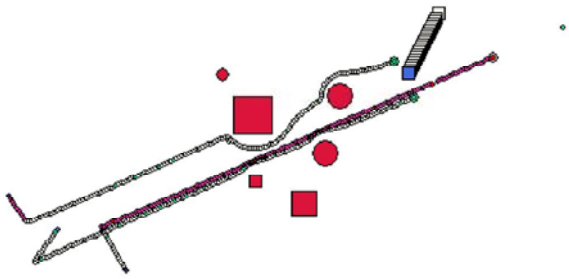


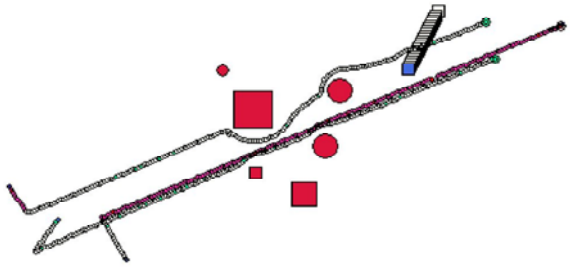
Fig.2 The Proposed Hybrid multi-robot formation control flow

Simulation and Analysis

The simulation test was operated in VC6.0. Having taken factors, such as the complexity of computing, highlight of results, and feasibility of realization, into account, we only set one dynamic obstacle in the complex environment simulation test, and the result is shown in Fig. 3. In Fig. 3, the dots are robots, the red graphic denotes the static obstacles and the blue graphic the dynamic obstacle, the red line represents the Leader robot's path and the white lines the other robots' path.



(a) The movement trace of avoiding obstacle



(b) The Proposed Hybrid formation control algorithm

Fig. 3 Multi-Robot Formation Control in Complex Environment

According to the above mentioned analysis, for the proposed hybrid formation control algorithm, the success rate of formation is 100 percent, the time consuming is 120s and the path length is 202. It

can be directly learned from Fig. 3 that the algorithm we proposed is efficient in the relatively complex environment containing both static and dynamic obstacles.

Conclusion

In this study, a PSO based multi-robot formation control algorithm is put forward. It is not only overcomes the shortcomings of the traditional Leader-Follower Algorithm that lack of formation feedback and the Artificial Potential Field Method that could not avoid robots obtaining local optimum, but also optimize the robots' relevant parameters online by PSO algorithm. For the environment that contains dynamic obstacles, the simulation result shows that the proposed method is effective and has demonstrated excellent adaptive ability and robustness.

References

[1] H. Chen, Research and implementation of multi-robot formation control, Harbin Institute of Technology, Harbin. (2011) 6-9.

[2] Zh. Su Ji. Lu. Formation feedback in behavior-based method used for keeping formation, Machine Tool. (2003) 167-169.

[3] M. Sisto, D. Gu, A fuzzy leader-follower approach to formation control of multiple mobile robots, IEEE/RSJ International Conference., USA. (2006) 2525-2520.

[4] B. Hao, Li. Qing, and Zh. Weng, Research on formation control for hybrid multi-robot based on leader-follower, Fire Control And Command Control. (2011) 5-8.

[5] X. Gao, L. Wu, W. Wei, Q. Wang and F. Xiao, Multi-robot formation control based on artificial potential field, Journal of Liaoning University of Science and Technology. (2014) 381-386.

[6] Q. Gao, X. Zheng, Z. Yi and S. Cheng, Multi-robot formation control with virtual leader based on PSO algorithm, journal of Wuhan University of Technology. (2010) 136-140.

[7] Z. Zhang, R. Zhang and X. Liu, Hybrid multi-robot formation control, Journal of Beijing university of post and telecommunication. (2008) 38-41.

[8] K. Qin, M. Sun and Z. Chang, Motion robot planning in dynamic environment based on improved artificial potential field method, Journal Of Sheng yang University Of Technology. (2004) 568-571.

[9] Z. Shi, J. Tu, and J. Wei, The simulation scenario for swarm robots based on open-source software player/stage, IEEE 2011 International Workshop OSSC. (2011) 107-113.

[10] L. Li and D. Li, Fuzzy entropy image segmentation based on particle swarm optimization, Progress in Natural Science. (2008) 1167-1171.

[11] E. Masechian and D. Sedighizadeh, A multi-objective PSO-based algorithm for robot path planning, on IEEE International Conference on Industrial Technology (ICIT). (2010) 465-470.