A Novel Method for Multiple Agent Formation Obstacle Avoidance Problem in the Complex Dynamic Environment

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Abstract: In order to solve the problem of multiple agent formation obstacle avoidance problem in the complex dynamic environment, the Ant Colony Rotational Vectorial Artificial Potential Field (ACRVAPF) method is proposed. Aiming to improve the global optimization ability of the agents, the obstacle avoidance result of the Ant Colony Optimization (ACO) is used for the pretreatment. The real-time ability is improved because of the vectorization of the Artificial Potential Field (APF) method, and the local minimum problem is solved because of the addition of rotational force. The feasibility and effectiveness of the proposed method is verified which the ACRVAPF method is better than the others.

Introduction

When the environment is too complex for a single agent to complete the certain task, multiple agents cooperate in order to accomplish the special task. The research of multiple agents become a hot topic in recent years. When multiple agents are collaborative to complete the task, the multiple agent formation cooperate to accomplish complex tasks [1]. Multiple agent formation in the special task, need to pass through the area that is full of obstacles and must solve the problem of multiple agent formation of obstacle avoidance [2-4]. After the multiple agent formation through the obstacle areas, they need to keep formation of multi-agent formation control. Therefore we need to realize multi-agent formation control and obstacle avoidance control at the same time.

There are a lot of solutions to the obstacle avoidance problem for multiple agent formation, such as reinforcement learning method [3, 5-6], swarm intelligence method, artificial potential field method [7-11], and fuzzy control method [12]. The artificial potential field method is to simulate nature of potential energy field, assuming that the action of force between agents, obstacles and target, and calculating the object by the force of the movement information.

The traditional artificial potential field method without information vector quantization to change the speed of agent, this article will vectorize agent speed and force, and then determine the acceleration vector resultant force vector and the velocity vector. This method let the agent automatically keep the original formation after formation through the obstacle region [13-15]. When solving the problem of obstacle avoidance, the agents are easy to fall into "local distress" by traditional artificial potential field method [16, 17] and wander in the obstacle area. In this paper, combining with loopback, the agent can bypass the dynamic obstacles and avoid "local distress" problem easily.

The global optimization ability of ant colony algorithm can be used for obstacle avoidance path for global optimization. But the real time is not enough, so it is used as a static planning offline. When the agent in the formal runtime, immediately start the rotational vectorial artificial potential field for obstacle avoidance after the dynamic obstacles detected.

Ant colony algorithm

Ant colony algorithm is always used to solve the problem of agent path planning and obstacle avoidance that is the global minimum searching ability bionics nonlinear optimization algorithm [18]. Ant colony algorithm set the rules with artificial simulated ants foraging, mobile and obstacle avoidance behavior, to solve the problem of robot, aircraft and underwater robot obstacle avoidance and path planning (route planning).

Mathematical model of ant colony algorithm. The probability of the path (i, j) is

$$P^k(i,j) = \begin{cases} \dfrac{[t\,(i,j)]^a \cdot [h\,(i,j)]^b}{\sum\limits_{s \notin t_k} [t\,(i,s)]^a \cdot [h\,(i,s)]^b}, & j \notin t_k \\ 0, & else \end{cases} \tag{1}$$

In the formula: $t\,(i,j)$ is the pheromone concentration of path (i, j), $h(i,j)$ is the inspired information, a and b are the relative importance of the pheromone and the heuristic information, the ant k has visited the path to the list t_k.

Update for 100 ants on the 10 route of pheromone concentration iterations

$$\begin{aligned} t_{ij}(t+n) &= r \cdot t_{ij}(t) + \Delta t_{ij} \\ \Delta t_{ij} &= \sum_{k=1}^{m} \Delta t_{ij}^{k} \end{aligned} \tag{2}$$

r ($r<1$) is the durability of the information, and

$$\Delta t_{ij}^{k} = \begin{cases} \dfrac{Q}{L_k}, ij \in l_k \\ 0, else \end{cases} \tag{3}$$

Q is the constant value, L_k is the length of the path, l_k is the ants k visited the path in the iteration.

The defects of ant colony algorithm. Using ant colony algorithm to solve the problem of intelligent obstacle avoidance has the advantage of global search, at the same time there are some defects: 1) Slow convergence speed; You can ignore the characteristics of slow convergence speed as the pretreatment to solve the problem of obstacle avoidance. Pretreatment can be used as offline obstacle avoidance planning, planning out a feasible obstacle avoidance path. 2) It is limited ability to solve the problem of multiple agent formation of obstacle avoidance. Using ant colony algorithm can only be planning out a obstacle avoidance path, unable to avoid collisions between multiple agent when the object is multiple agent formation. It is unable to avoid the problem of collision between multiple agent formations, and to solve the problem of multiple agent formation control and obstacle avoidance control at the same time.

Artificial potential field method

Artificial potential field method is to simulate the physical phenomenon of intelligent obstacle avoidance and intelligent path planning algorithm that strong ability of real-time processing [19-20].

Mathematical model of artificial potential field method. Potential field as a virtual force field, fictional the obstacles existing in agent repulsion to avoid obstacles when the artificial potential field method is adopted to solve the problem of intelligent obstacle avoidance; and fictitious the target for agent is attractive to reaching goals. Principle diagram is shown in Fig.1.

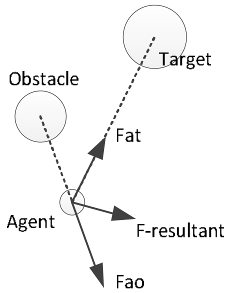


Fig.1 The principle of artificial potential field method

Agent by force as the goal of the gravity of F_{at} and obstacles to the sum of the repulsive force of F_{ao} :

$$F_a = F_{at} + F_{ao} \tag{4}$$

After determine the force direction, agent moved to direction of force according to the set speed v_a , $v_a d_t$ is the moving distance, d_t is the simulation step.

The defects of artificial potential field method. Using artificial potential field method to solve the problem of agent of obstacle avoidance has the advantage of rapidity, at the same time there are some defects: 1) Weak global search capability; An agent use the local information only search to the surrounding and the obstacles within a certain range. 2) Easy trapped in local distress; Agent will constantly hovering between these obstacles, thus unable to through the obstacles when obstacles to a particular distribution of the region. 3) Considering formation control and obstacle avoidance control at the same time need to be improved. Using artificial potential field method for formation control and obstacle avoidance control at the same time when considered by the mutual action between agents.

Ant colony rotational vectorial artificial potential field method

In order to solve the problem of multiple agent formation obstacle avoidance problem in the complex dynamic environment, and have the characteristic of global search ability and real-time processing ability strong, the ant colony rotational vectorial artificial potential field method is proposed.

The proposed of Ant Colony Rotational Vectorial Artificial Potential Field. Using ant colony algorithm to pretreatment; In the case of agent understand the global information, using ant colony to obstacle avoidance planning, environmental planning of static out a obstacle avoidance path before running the official obstacle avoidance.

Add the loopback force in the resultant force. To add a loopback force perpendicular to the repulsion force to solve the problem of the agent into the local distress, one side of the direction to have a goal. To avoid the agent wandering through happens between obstacles.

The speed of the agent for variable vector and considering the force between agents at the same time. To solve the problem of formation control problem of multiple agent formation, the agent's speed to variable velocity vector, in the resultant force to add forces between the agents making multiple agent automatically maintain a set of formation. Speed and force information are vector information.

The Algorithm steps of Ant Colony Rotational Vectorial Artificial Potential Field. In order to solve the problem of multiple agent formation obstacle avoidance problem in the complex dynamic environment. The algorithm steps of ant colony rotational vectorial artificial potential field are:

Step1: Initialize variables of ant colony algorithm and obstacle environment, such as a b , the pheromone matrix, coefficient and so on, initialize a position of a starting point and a target point;

Step2: Using ant colony algorithm to optimize computing, according to the formula (1) update iteration;

Step3: To obtain a static environment path after end of the iteration.

Step4: Start the multiple agent formation of obstacle avoidance, the lead agent to follow the path of Step3 result;

Step5: Within the scope of the agent of visualization, if there is a dynamic obstacles, the start Step6, otherwise back to Step4;

Step6: Launched the rotational vectorial artificial potential field method, calculation agent position at the next time is

$$p_{anew} = p_{aold} + \vec{v}_{anew} d_t \tag{5}$$

p_{aold} is the agent current time location, d_t is the simulation step size, the velocity vector of agent is

$$\begin{gathered}\vec{v}_{anew} = \begin{cases} \vec{v}_{aold} + \vec{a}_a * d_t, & v_a \le \left|\vec{v}_{a\max}\right| \\ \vec{v}_{aold}, & v_a > \left|\vec{v}_{a\max}\right| \end{cases} \\ v_a = \left|\vec{v}_{aold} + \vec{a}_a * d_t\right| \end{gathered} \tag{6}$$

$\vec{v}_{aold}$ is the current velocity vectors of agent, v_a is the computing speed scalar, $\left|\vec{v}_{a\max}\right|$ is the velocity vector scalar of maximum limit, the acceleration vector is

$$\vec{a}_a = \frac{\vec{f}_{join}}{m_a} = \frac{(\vec{f}_{ao} + \vec{f}_{aa} + \vec{f}_{at} + \vec{f}_{ac})}{m_a} \tag{7}$$

$\vec{f}_{join}$ is the resultant force vector of agent, m_a is the virtual mass of agent.

In formula (7), the repulsive force vector of obstacles to agent is

$$\begin{gathered}\vec{f}_{ao} = \begin{cases} C, & r_{ao} \in D \\ +\infty, & r_{ao} \in [0, s_{o\min}) \\ 0, & else \end{cases} \\ C = \vec{V}_{ao} * m_a * m_o * k_{fao} * \left(\frac{1}{r_{ao}} - \frac{1}{s_{o\max}}\right)^2 \\ D = [\max\{s_{o\min}, s_{a\min}\}, \min\{s_{o\max}, s_{a\max}\}] \end{gathered} \tag{8}$$

r_{ao} is the distance between the agent and the obstacle, $s_{o\min}$ is the obstacle distance of minimum threat, $s_{o\max}$ is the obstacle distance of maximum threat, $s_{a\min}$ is the agent distance of minimum visual, $s_{a\max}$ is the agent distance of maximum visual, m_o is the virtual mass of obstacle, $\vec{V}_{ao}$ is the repulsion between the agent and obstacles vector, k_{fao} is the repulsive force factor.

In formula (7), the gravity vector of goal to agent is

$$\vec{f}_{at} = k_{fat} * r_{at} * \vec{V}_{at} \tag{9}$$

k_{fat} is the gravity factor, r_{at} is the distance between agent and target, $\vec{V}_{at}$ is the gravity vector between agent and target.

In formula (7), the force vector between agents is

$$\begin{gathered}\vec{f}_{aa} = \begin{cases} E, & r_{aa} \in [s_{a\min}, s_{a\max}] \\ 0, & r_{aa} \notin [s_{a\min}, s_{a\max}] \end{cases} \\ E = \vec{V}_{aa} * k_{faa} * m_a^2 * \left(\frac{1}{r_{aa}} - \frac{1}{d_a}\right)^2 \end{gathered} \tag{10}$$

r_{aa} is the distance between multiple agents, d_a is the formation of the ideal distance between agents, k_{faa} is the agent inter-atomic forces factor, $\vec{V}_{aa}$ is the force vector between the agent.

In formula (7), the loopback force vector of agent is

$$\vec{f}_{ac} = \begin{cases} \vec{G}, r_{ao} \le k_{rac} * s_{o\min} \\ 0, r_{ao} > k_{rac} * s_{o\min} \end{cases} \qquad (11)$$
$$\vec{G} = \vec{V}_{ac} * k_{ac} * f_{ao} * m_a * m_o$$

k_{rac} is the loopback force distance impact factor, k_{ac} is the loop power factor, $\vec{V}_{ac}$ is the loopback force vector of agent, f_{ao} is the repulsion force value of agent.

This loopback force in order to avoid agent in local distress, The direction of the loopback force diagram as shown in Fig.2, agent (Agent) suffered loopback force was "F_{ac1}" when target at "Target1", otherwise was "F_{ac2}".

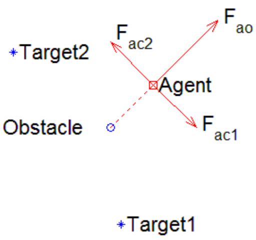


Fig.2 View of the rotational force direction

Step7: After launched the rotational vectorial artificial potential field method, will make the agent migrate from the path of the off-line programming, At this point to continue use rotational vectorial artificial potential field method for obstacle avoidance and formation control, stop counting until agent reach target, otherwise continue Step6.

Numerical Simulation

Respectively to compare the advantages and disadvantages of each method, using artificial potential field method, rotational vectorial artificial potential field method, ant colony rotational vectorial artificial potential field method for multiple agent formation of numerical simulation of obstacle avoidance.

Under the coordinates of Windows system, red boxes represents the agent, green asterisk represents the target, blue boundary graphical represents the obstacle, curve and the dashed line represents the path of agent, the following simulation using MATLAB software.

Design the obstacle environment in two-dimensional space before simulation, design the shape obstacles, such as round, hexagonal, T-shaped, L-shaped and arbitrary shape. Among them, L-shape and T-shape can make complex obstacle environment, Agent must bypass the various shapes to reach the target point.

The contrast of artificial potential field method and rotational vectorial artificial potential field method. For the analysis the impact of in the resultant force add the force action to agent, compared the obstacle avoidance effect of artificial potential field method and rotational vectorial artificial potential field method, and the effect is shown in Fig.3.

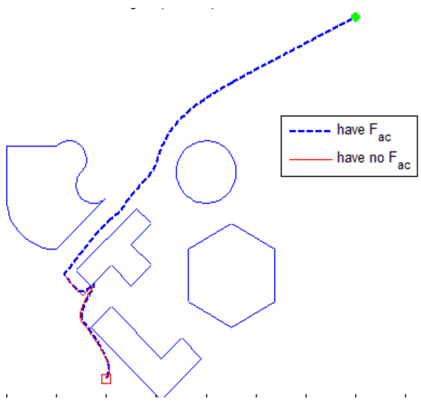
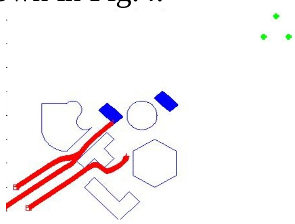


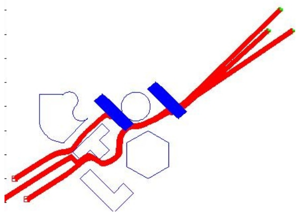
Fig.3 Example of the rotational force have or not

It can be seen from the Fig.3: Agent can not pass the obstacle areas (the red solid line) without loopback force. Agents have passed the obstacle area (blue dotted line) after add the loopback force. Therefore, the necessity of adding loopback force in resultant force is verified.

The contrast of Ant Colony Optimization and ant colony rotational vectorial artificial potential field method. Design the simulation environment of existing mobile obstacles (the blue square is moving obstacles), Compared to deal with the problem of multiple agent formation of obstacle avoidance of ant colony optimization method and the ant colony rotational vectorial artificial potential field method. As shown in Fig.4.



(a) Ant colony optimization



(b) Ant colony rotational vectorial artificial potential field method

Fig.4 Example of the rotational vectorial artificial potential method have or not

It can be seen from Fig.4 (a), agent can't avoid the portable dynamic obstacles after using ant colony algorithm to static planning, while using Ant colony rotational vectorial artificial potential field method, agent avoid the obstacles, Fig.4(b). Maintain the agent's fleet formation after multiple agent formation through the obstacle areas. The simulation results demonstrate the ant colony rotational vectorial artificial potential field method is used to solve the problem of multi-agent formation of obstacle avoidance is feasibility and validity.

Obstacle avoidance simulation under the complex dynamic environment. Under the complex dynamic environment, mobile and immobile obstacle is full of obstacles in the area, made up of 15 agents multi-agent formation under the environment of complex dynamic obstacle avoidance simulation, as shown in Fig.5.

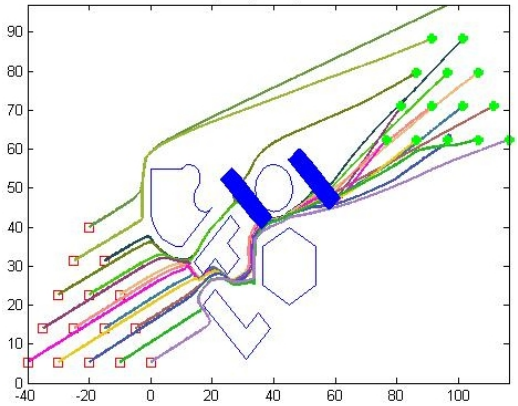


Fig.5 The numerical simulation of obstacle avoidance problem in the complex dynamic environment

It can be seen from Fig.5, made up of 15 agents multi-agent formation in complex dynamic environment has passed the obstacle areas, maintain the agent's fleet formation after multiple agent formation through the obstacle areas. The simulation results demonstrate the ant colony rotational vectorial artificial potential field method, being used to solve the problem of multi-agent formation of obstacle avoidance problem in the complex dynamic environment, is feasibility and validity.

Conclusions

1. Multiple agent formation of obstacle avoidance in the complex dynamic environment numerical simulation experiment, the intelligent body formation through the obstacle area, avoid the local distress situation, and maintain the agent's fleet formation after multiple agent formation through the obstacle areas, demonstrate the ant colony rotational vectorial artificial potential field method is feasibility and validity.
2. The proposed method is verified and has strong global optimization ability and real-time processing ability.

Parameters should have the ability of adaptive adjustment in the research on the algorithm of more intelligent. Extending to three-dimensional space to solve the problem of obstacle avoidance is needed to do further research.

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