International Journal of Control and Automation
Vol.8, No.3 (2015), pp.67-74
http://dx.doi.org/10.14257/ijca.2015.8.3.09

Obstacle Avoidance with Formation Kept for Multi-agent

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Abstract

In this paper, we present a new approach to obstacle avoidance for a group of agents moving in a formation. The goal of the group is to move through a partially unknown environment with obstacles and keep the formation until they have reached the destination. The approach proposed treats the multi-agent in the formation as a whole, and sets a free region for all the agents, in which the agents can keep the formation and avoid the obstacles. Consequently, the problem of obstacle avoidance of each agent is transformed to the problem for the leader to look for the free region around the obstacles. We illustrate the method with an example. The simulation results show the feasibility of the proposed obstacle avoidance method.

Keywords: *obstacle avoidance, formation, multi-agent, free region, leader-followers*

1. Introduction

Nowadays, flocking with obstacle avoidance of multi-agent has attracted many researchers' interests and get many results [1-4]. However many researches focused on the obstacle avoidance of a single agent. With the increasing requests on the application of multi-agent for complex tasks, the obstacle avoidance of multi-agent systems becomes more and more crucial.

In some applications, it requests multi-agent to have the ability to avoid obstacle while keeping formation. In this paper, we will discuss this topic. There are 3 common flocking methods [5-7], including the leader-follower schemes, behavior-based methods, and virtual structure techniques. In this paper, we will adopt the leader-follower scheme, and the details will be introduced in Section 2.

Obstacle avoidance is another well-studied problem in flocking of multi-agent [8-10]. There are many algorithms, including Artificial Potential Field method, Visual Graph method, Grid method, C-Space method. In this paper, free region is proposed to integrate with artificial potential field method, and used to realize obstacle avoidance of multi- agent systems while keeping formation. The fundamental idea will be introduced in section 3.

This paper presents obstacle avoidance of multi-agent keeping formation in the partially unknown environment. With the leader-follower algorithm, multi-agent system is required to keep the formation until to the destination. A new obstacle avoidance method is proposed to set a free region for all the agents, let the leader agent detect obstacles and plan the path in which the follower agent could avoid the obstacles while keeping the formation. Under this scheme, the leader agent and the follower agents are treated as a whole. When the leader agent detects a obstacle, it plans the path not only for itself but for the follower agents to pass through.

ISSN: 2005-4297 IJCA

An outline of the paper is as follows: In section 2, the problem of flocking of multi-agent and formation of leader-follower algorithm are established. In section 3 the obstacle avoidance approach is presented. In section 4, the simulation results are provided to validate the effectiveness of the proposed approach. Finally, Section 5 concludes the paper and outlines some future research directions.

2. Leader-follower based Formation

The fundamental idea of leader-follower based formation is that, in a group of multiple agents, one is assigned as the leader and others are followers. The task of leader is to lead the entire formation to the destination. The task of follower is to reach the destination following the leader. The goal of the formation control is that the follower tracks the leader with a desired distance and a desired relative speed. In this paper, one leader agent with 2 follower agents based formation is considered as indicated in Figure 1.

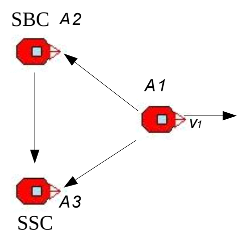

Figure 1. Formation of 3 Agents

Figure 1 shows the formation structure. A1 (Agent 1) is the leader agent, and moves in a predefined trajectory. A2 (Agent 2) and A3 (Agent 3) are the follower agents. A2 employs SBC strategy [11], so it only maintains its separation and bearing with respect to A1. A3 employs SSC strategy, maintaining its separation from A1 and A2. The following and controlling relationship of the 3 agents is as following: $A2 \leftarrow A1$ (A2 is controlled by A1), $A3 \leftarrow \begin{cases} A1 \\ A2 \end{cases}$ (A3 is controlled by A1 an A2).

The dynamic equation of Agent 1 is given as follows.

$$\begin{cases} \dot{x}_1 = v_1 \cos\theta_1 \\ \dot{y}_1 = v_1 \sin\theta_1 \\ \dot{\theta}_1 = \omega_1 \end{cases} \tag{1}$$

where, $[x_1, y_1, \theta_1]$ is the position of Agent 1, v_1 is the linear speed , ω_1 is the angular speed of Agent 1.

The dynamic equation of Agent 2 is given as follows.

$$\begin{cases} \dot{l}_{12} = v_2 \cos\gamma_1 - v_1 \cos\varphi_{12} + d\omega_2 \sin\gamma_1 \\ \dot{\varphi}_{12} = \dot{l}_{12}\{v_1 \sin\varphi_{12} - v_2 \sin\gamma_1 + d\omega_2 \cos\gamma_1 - l_{12}\omega_1\} \\ \dot{\theta}_2 = \omega_2 \end{cases} \tag{2}$$

where, $\gamma_1 = \theta_1 - \varphi_{12} - \theta_2$. $[l_{12}, \varphi_{12}, \theta_2]$ is the position of Agent 2. v_2 is the linear speed, ω_2 is the angular speed of Agent 2。

The dynamic equation of Agent 2 is given as follows.

$$\begin{cases} \dot{l}_{13} = v_3 \cos\gamma_1 - v_1 \cos\varphi_{13} + d\omega_3 \sin\gamma_1 \\ \dot{l}_{23} = v_3 \cos\gamma_2 - v_2 \cos\varphi_{23} + d\omega_3 \sin\gamma_2 \\ \dot{\theta}_3 = \omega_3 \end{cases} \quad (3)$$

where, $\gamma_2 = \theta_2 - \varphi_{23} - \theta_3$. $[l_{23}, \varphi_{23}, \theta_3]$ is the position of Agent 3. v_3 is the linear speed, ω_3 is the angular speed of Agent 3.

Define when the formation tends to be stable, the distance between any two agents satisfies the following constraints:

$$l_{12} = l_{13} = l_{23} = d \quad (4)$$

where, d is the distance value between two agents. According to the features of the leader-follower formation, the mission of A1 is to move in a predefined trajectory, and avoid the obstacles. The missions of A2 and A3 are to follow the leader with no need to know the destination and the information of the obstacles. Therefore, when any obstacle is detected, as long as A1 can select the suitable route, A2 and A3 only need to keep the formation to avoid the obstacle.

3. Obstacle Avoidance of Multi-agent while Keeping Formation

Based on the previous research, A1 selects the obstacle avoidance route without taking into account the obstacle avoidance of A2 and A3. A2 and A3 should avoid obstacles by themselves [12-13]. In many cases, these obstacle avoidance approaches, on one hand, will lead to dismiss of the formation, on the other hand, can't guarantee the obstacle avoidance of A2 and A3.

The paper focuses on the obstacle avoidance problem when multiple agents move together and keep a constant formation during the movement, for example the leader-follower based formation shown in Figure 1. One assumption is that the formation can be maintained during the movement. The obstacle detection and avoidance can be accomplished by the leader. Then the problem of multiple agents avoiding obstacles is simplified as the problem of the leader's obstacle avoidance problem. But the difference from the previous obstacle avoidance algorithms is that in this paper, under the assumption of keeping a constant formation for the group movement, the leader cannot simply consider whether it can avoid the obstacles, or the problem of multiple agents avoiding obstacles by dismissing their formation. It focuses on the problem whether the agents group can avoid obstacles in a constant formation. During the movement, the leader will guide the followers. When the leader detects the obstacles, first of all it will check the feasibility of its obstacle avoidance, then check if other agents in the group can avoid the obstacles, finally plan a collision-free route for this group.

When the distance between an agent and an obstacle is assumed to be larger than or equal ε , the agent can successfully avoid the obstacle. As shown in Figure 2, a free region for group movement is constructed, assuming the leader agent as an axis and considering one agent as a particle. The obstacles located outside of the region will not have a chance to collide with the agents in the region.

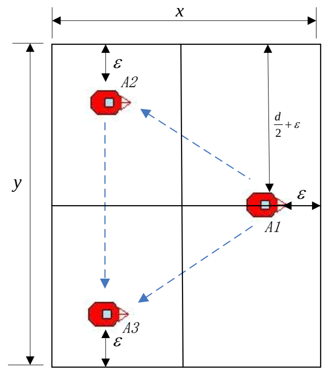

Figure 2. Configuration of Free Region

The configuration of free region is given in Figure 2. Where,

$$x = \frac{\sqrt{3}}{2} d + 2\varepsilon \tag{5}$$

$$y = d + 2\varepsilon \tag{6}$$

It is obvious that if and only if the multi-agent moves inside the free region, the agents can successfully avoid the obstacle under the leader's guidance.

In this paper, we propose an obstacle avoidance algorithm on the base of the problem formulation and results in [4]. The leader, obstacle and free region are depicted in Figure 3.

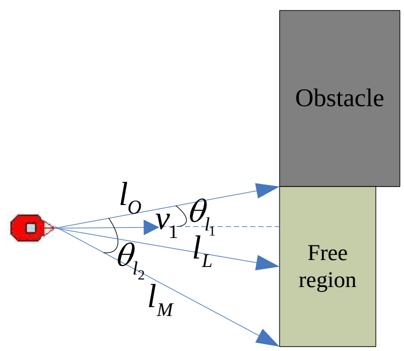

Figure 3. Leader with Obstacle Avoidance

As shown in Figure 3, if the problem of the obstacle avoidance of the followers is ignored, when the leader moves along a straight line, keeping the current movement direction can avoid the obstacles. But if the problem of the obstacle avoidance of the followers is considered, it is important to find a feasible and reliable movement region for the followers passing through in the neighbor of the obstacles. This region is called free region, shown as a green part in the Figure 3. The size of the region is decided based on the Figure 2. If there is enough collision-free space around the obstacles for the agents group to pass, then the leader will guide these followers to pass by adjusting to an appropriate direction.

In Figure 3, l_O is the distance of leader to the obstacle. l_M is the maximum distance of leader to the free region. l_L is the distance of leader to the center of free region . θ_{l_1} is the angle between v_1 and l_O . θ_{l_2} is the angle between l_O and l_S .

If

$$\sqrt{l_O^{\ 2} + l_S^{\ 2} - 2 l_O l_S \cos\theta_{l_2}} \geq d + 2\varepsilon \tag{7}$$

then, the minimum distance the leader need to move is $D_m = d + 2\varepsilon - l_O \times \sin\theta_{l_1}$. And, the leader will guide the followers to adjust the route.

The obstacle avoidance algorithms are summarized as follows.

Table 1. The Algorithm of Obstacle Avoidance with Formation

Step1: Detecting Obstacle

In this progress, leader detects if there are obstacles around the formation.

If no, then keep moving in formation. If yes, then go to step2.

Step2: Looking for free region

According to $\sqrt{l_O^{\ 2} + l_S^{\ 2} - 2 l_O l_S \cos\theta_{l_2}} \geq d + 2\varepsilon$, free region is identified.

If there is no free region, the leader should keep looking for.

If there is a free region, then go to step3.

Step3: Avoiding obstacle

The leader should lead the followers to adjust the motion plan to enter the free region to avoid the obstacle.

Step4: Going to the destination

After avoiding all the obstacles, leader should lead the followers to the destination.

Do they reach the destination? Yes to ending. No to Step1.

4. Simulation and Results

The simulation model of 3 amigo mobile robots is prepared using the Matlab/Simulink environment. Each robot is regarded as an agent. The original positions and the obstacles are shown in Figure 4. It is assumed that the multiply robots move with uniform velocity. Under normal condition, the multiply robots in the formation can move with uniform velocity until reaching the destination. The time period begins from the formation being generated. The original positions of 3 robots are (22.3, 110), (5,120), (5,100).

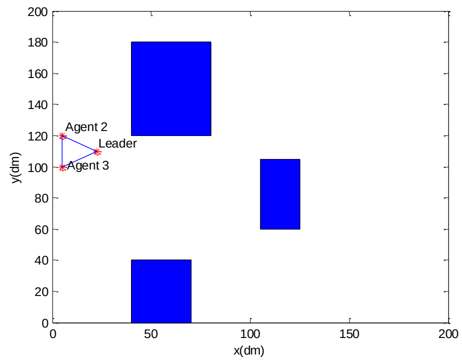

Figure 4. The Simulation Environment

As comparison, the motion curve of the leader moving alone is given in Figure 5. We can see that there is enough space for the leader to pass through. So the leader can avoid obstacles without changing the initial motion plan.

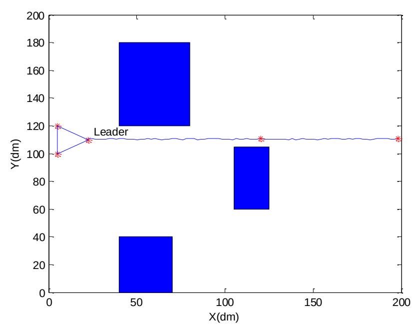

Figure 5. Obstacle Avoidance of Leader Agent Individually

Figure 6 shows a collision-free route for multi-agent. As it can be seen from the Figure, the proposed approach can help the multi-agent to avoid obstacles, maintaining a formation. Compared with Figure 5, the time required for reaching the destination take longer. The route is also adjusted in a multiple times in terms of the locations of the obstacles. These prices are acceptable for the goal of maintaining the group's formation during the movement.

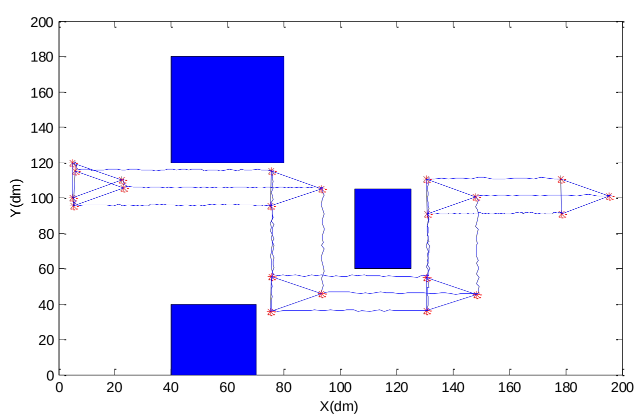

Figure 6. Obstacle Avoidance with Formation Kept

The free region is defined as a rectangle in the context. In reality, this free region can be defined as a circle or other shapes. But the computation of the free region needs a slight adjust. Additionally, the definition of the free region involves the selection of the threshold value ε. If ε is too large, then the potential space for avoiding obstacles will be reduced. If ε is too small, obstacle collision avoidance will possibly failure. Therefore, the selection of a proper ε will play a critical role in the future work.

5. Conclusions

We have considered the problem of obstacle avoidance for multi-agent with formation kept. Based on a free region, a new obstacle avoidance method is proposed to transform the problem of obstacle avoidance for each agent to the problem of obstacle avoidance for the leader agent. Once the leader can find the free region around the obstacles, it can lead the followers to avoid the obstacles while keeping the formation. The simulation results demonstrate the effectiveness of the proposed method. In the future research, we will further consider the selection of the threshold value ε and more complicate environment with various obstacles.

Acknowledgements

This work is supported by the Ningbo Natural Science Foundation (Grant No.2012A610010, 2013A610070), The Science and Technology Innovation Team of Ningbo (Grant No.2012B82006, 2013B82009), and Zhejiang Provincial Educational Commission Foundation (Y201122103).

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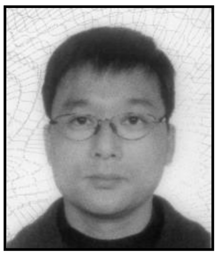

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