The analysis and avoidance of fault agent in flocking of multi-agent

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Abstract

In the last decade considerable research efforts have been spent to the motion of flocking of multi-agent. Special attention has been put in the applications, especially for those operations in real environment where a high degree of safety as well as self-diagnostics capabilities are required. The development of effective strategies of fault diagnosis for flocking of multi-agent is a critical research task. In this paper, the flocking motion of multi-agent with a leader is studied. When flocking in the real environment, it is inevitable for agents to occur faults. The faults occurred in different agent will lead to different effects for flocking. According to the variety of the velocity of agents, the fault types are classified. A fault agent avoidance method is proposed and implemented in a multi-agent flocking system. The simulation results show the method can help the agents to avoid the fault agent.

Keywords: multi-agent, flocking, fault agent, fault agent avoidance, leader

1 Introduction

As advancing the research of flocking of multi-agent, the flocking motion is asked for higher requirements on its safety and reliability [1-5]. In reality, it is inevitable that some faults may happen to agents during the motion of flocking. It is the challenge that the research of flocking of multi-agent has to face. During the motion, multi-agent cannot form a stable formation and will continue unpredictably and erroneously, if the fault agent cannot be detected or other functional agents cannot avoid the fault agent in time. As a result, the flocking cannot complete the scheduled tasks successfully. Or more possibly, more serious damages may occur.

During the motion of flocking of multi-agent, once one of the agents has failure, the caused chain reaction will lead to the malfunctions happening to other agents. Therefore, the foundation of the application of flocking of multi-agent in real life is to analyze the effects of fault agent imposing on other agents, timely obtain a complete knowledge of the fault agent and correctly handle it, and guide other agents to continue the motion. But the existing literatures about flocking of multi-agent seldom focus on the problem of handling fault agents in flocking of multi-agent [6-9].

The fault in different agents of flocking will play distinct effects on the motion of flocking. Selecting the most effective approach to solve problems based on the natures of the fault agents is a good way for the flocking to accomplish the tasks.

This paper focuses on classifying and analysing the fault agents according to their roles and importance in the motion of flocking, and proposes a systemic approach for the multi-agent to avoid the fault agent.

2 Flocking of multi-agents with a leader

The topology structure of multi-agent system is represented by the neighbouring graph $G=(V,E)$ [9-11]. And the neighbouring graph is defined to be an undirected graph consisting of a set of vertices $V=\{n_1,n_2 L ,n_n\}$, whose elements represent agents in the group, and a set of edges $E=\{(n_i,n_j)\in V\cdot V \mid n_i \sim n_j\}$ containing unordered pairs of vertices that represent neighbouring relations at time *t*. Considering N agents, the motion of each agent is denoted as,

$$\begin{cases}\dot{r}_i = v_i \\ \dot{v}_i = u_i\end{cases}, \ i = 1,2, \quad ,N, \tag{1}$$

where, $r_i \in R^2$ is the position vector of Agent *i*. $v_i \in\sim R^2$ is the velocity vector of Agent *i*. $u_i \in\sim R^2$ is the control input acting on Agent *i*. $r_{ij}=r_i-r_j$ is the position difference vector.

In order to describe the spatial order of the desired configuration of flocking in a proper analytical framework, to avoid collision with other agents, each agent should keep a safety distance from its neighbours. Then, we define the coupling constraints as that for agent *i* and *j* [12, 13],

$$\left\| r_i - r_j \right\| = d \ , \tag{2}$$

where, $\|\cdot\|$ is the Euclidean norm. We assume that the relative distance between agents will be *d*. The speed and direction of movement of each agent will approach the same.

The fundamental idea of flocking with leader-followers model is that, in a group of multiple agents, one

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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 is that the follower tracks the leader with a desired distance and a desired relative speed. In this paper, one leader agent with 5 follower agents based formation is considered as indicated in Figure 1.

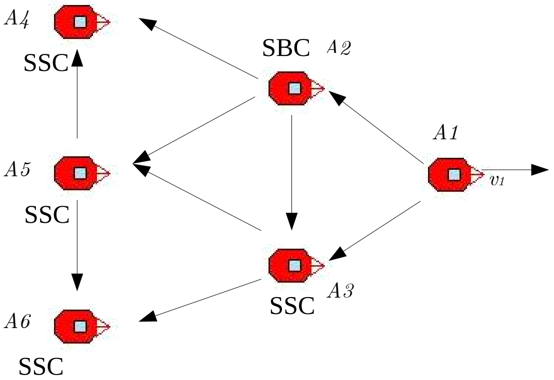


FIGURE 1 Flocking of multi-agent with a leader

Figure 1 shows the flocking model. *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, so it only maintains its separation and bearing with respect to *A1*, *A3*, *A4*, *A5* and *A6* employ SSC strategy, maintaining its separation from *A1*, *A2* or *A3* [14-16]. The following and controlling relationship of the 6 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*), $A4 \leftarrow \begin{cases} A2 \\ A5 \end{cases}$, $A5 \leftarrow \begin{cases} A2 \\ A3 \end{cases}$, $A6 \leftarrow \begin{cases} A3 \\ A5 \end{cases}$.

The dynamic equation of Agent 1 is given as follows,

$$\begin{cases} \dot{x}_1 = v_1 \cos\theta_1 \\ \dot{y}_1 = v_1 \sin\theta_1 \\ \dot{\theta}_1 = \omega_1 \end{cases}, \tag{3}$$

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,

$$\begin{cases} \dot{l}_{12} = v_2 \cos\gamma_1 - v_1 \cos\varphi_{12} + d\omega_2 \sin\gamma_1 \\ \dot{\varphi}_{12} = \dot{l}_{12} \left\{ v_1 \sin\varphi_{12} - v_2 \sin\gamma_1 + d\omega_2 \cos\gamma_1 - l_{12}\omega_1 \right\} \\ \dot{\theta}_2 = \omega_2 \end{cases}, \tag{4}$$

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 3 is given as follows:

$$\begin{cases} \dot{l}_{13} = v_3 \cos\gamma_1 - v_1 \cos\varphi_{13} + d\omega_3 \sin\gamma_1 \\ \dot{l}_{23} = v_3 \cos\gamma_2 - v_2 \cos\varphi_{23} + d\omega_3 \sin\gamma_2 \\ \dot{\theta}_3 = \omega_3 \end{cases}, \tag{5}$$

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. The dynamic equations of other agents can be deduced by analogy.

3 Fault types in flocking of multi-agent

The velocity and position of each agent are vitally important in the motion of flocking. In this paper, faults are classified by the difference of the velocity of each agent. According to Figure 1, there are two types of agent, leader fault and follower fault. We classify the faults into two situations, leader fault and follower fault.

The definition of the two situations is explained as follows.

3.1 FAULT OF LEADER

In the motion of flocking, the task of leader is to lead the entire formation to the destination. Once the leader malfunctions, it will not be able to fulfil the task. The threshold value range of normal movement velocity of agent is set to be $[\varepsilon_1, \varepsilon_2]$. Then, three fault types are discussed according to the linear velocity of leader as follows.

1) $0 \le v_1^k < \varepsilon_1$, where v_1^k is the linear velocity of leader. $v_1^k = 0$ represents two possible cases. One case is the malfunction of the communication module of leader. Since other agents cannot receive the motion information of leader, they will consider the velocity of leader to be 0. Other case is the malfunction of the mechanical module, which will bring leader to a stop. In both cases, other agents will follow leader to a stop. This will cause the task to fail.

$0 < v_1^k < \varepsilon_1$ represents that the velocity of leader is below the normal range. Other agents will not be able to reduce the speed to follow leader, and leader will obstruct the motion of other agents. In this case, leader is considered to be faulty, and be the obstacle of other agents.

2) $\varepsilon_1 < v_1^k < \varepsilon_2$. In this case, although the velocity of leader is different from the normal one, it still in the threshold value range. In order to fulfil the task, other agents will adjust their motion speed to follow leader.

3) $v_1^k < \varepsilon_2$. In this case, the velocity of leader is beyond the threshold value range. Other agents cannot follow leader to move in so high speed. So, the leader is considered to be faulty. However, if the direction of motion is remained unchanged, the leader will not obstruct the motion of other agents.

3.2 FAULT OF FOLLOWER AGENT I (I=2,3,4,5,6)

1) $0 \le v_1^k < \varepsilon_1$, where $v_1^k = 0$ represents two possible cases. One case is the malfunction of the communication module of Agent *i*. Since other agents cannot receive the motion information of Agent *i*, they will consider the velocity of Agent *i* to be 0. Other case is the malfunction of the mechanical module, which will bring Agent i to a stop. In both cases, Agent *j*（$j < i$）will not be affected by Agent *i* and keep moving, and Agent *k*（$k > i$）will obstructed by Agent *i*.

$0 < v_1^k < \varepsilon_1$ represents that the velocity of Agent *i* is below the normal range. Leader and other agents will not able to reduce the speed, and Agent *i* will obstruct the motion of other agents. In this case, Agent *i* is considered to be faulty, and be the obstacle of other agents.

2) $\varepsilon_1 < v_1^k < \varepsilon_2$. In the case, although the velocity of Agent *i* is different from the normal one, but it still in the threshold value range. Since Agent *i* is one of the followers, Agent *j (j < i)* can continue moving at the normal speed, while Agent *k (k > i)* need to adjust the motion speed affected by Agent *i*. Then difference motion speed will caused the dismiss of flocking. So Agent *i* is set to be a obstacle in this paper.

3) $v_1^k < \varepsilon_2$ represents the velocity of Agent *i* is beyond the threshold value range. Other agents cannot follow Agent *i* to move in high speed. So, the Agent *i* is considered to be faulty. Owing to the high speed, Agent *i* will crash into the front Agents. And Agent *i* is set to be a obstacle for other agents in this case.

4 Fault agent diagnosis and avoidance

According to the above analysis, the fault agent avoidance method is given as follows.

1) When the leader has been faulty, the flocking will not be able to continue due to the loss of the leader. So the top priority is to select new leader in the remains. This paper uses the shortest distance approach to choose new leader to continue the motion of flocking, such as Agent 2 in Figure 2 as a new leader. After the selection of new leader, the follow strategy has to make a change correspondingly to maintain the shape of flocking, shown in Figure 2.

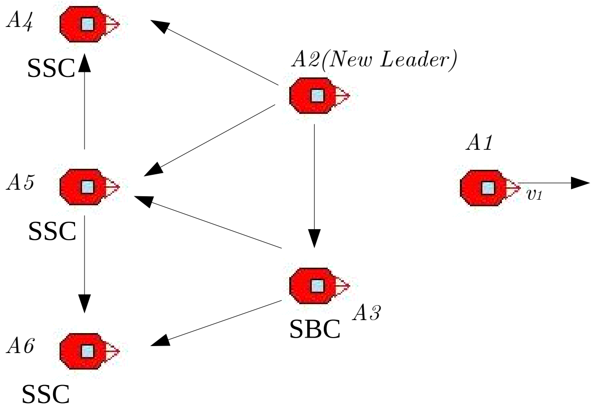


FIGURE 2 Flocking model of multi-agent with a new leader and a fault leader

Compared with Figure 1, Figure 2 shows a modification of the follow strategies on Agent 2 and Agent 3. Agent 4, 5 and 6 do not have any change. Shortly after the new leader and the new follow strategies have defined, the focus of flocking is to avoid Agent 1. There already have lots of literatures about the methods of avoiding obstacles. In terms of the complexity of routes of the flocking, different methods can apply.

2) When Agent *i* has malfunctions, it will affect the agents that have follow relations with Agent *i*. It is necessary to modify the follow strategy. Take an example of Agent 2 with malfunctions, as shown in Figure 3. As it can be seen from the comparison of Figures 1 and 3, the follow strategies of Agent 3 and Agent 4 need a quick modification when malfunctions occur in Agent 2. Agent 5 and 6 do not need a change of the strategies. When the new model of the flocking is defined, the flocking will start the avoidance process of Agent 2 by following the leader.

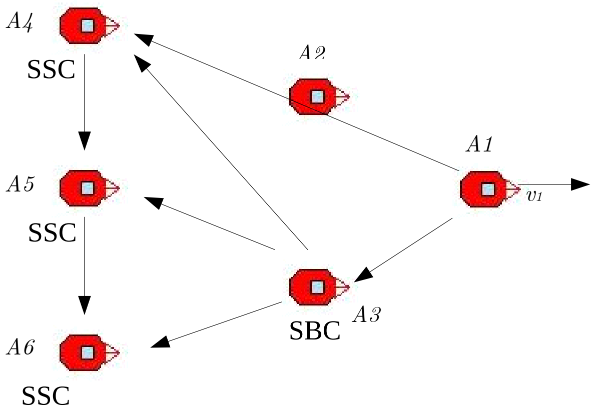


FIGURE 3 Flocking model with fault Agent 2

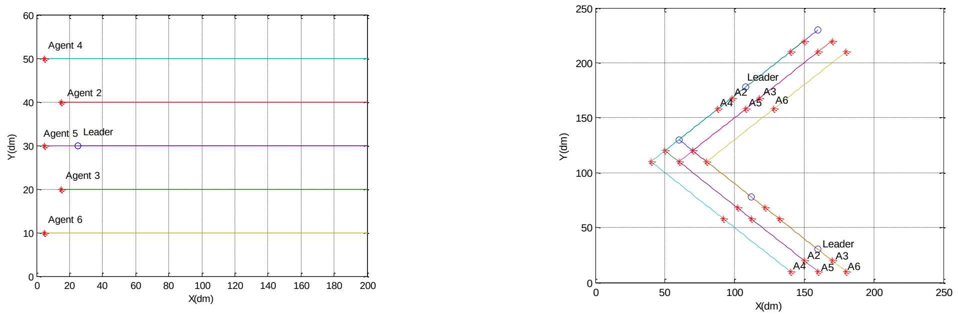
In summary, the algorithm of the fault agent diagnosis and avoidance for flocking of multi-agent is shown in Table 1.

TABLE 1 Fault diagnosis and obstacle avoidance algorithm of multi-agent

```
Initialization
Set the follow strategy as SBC (A_1, A_2, l_12, φ_12) and SCC (A_i, A_j, A_k, l_ij, l_ik) (i,j,k=2,3,4,5,6)
% Fault diagnosis and obstacle avoidance algorithm of Leader
for k=1 to maxsteps
        for i=1
                if 0 ≤ v_1^k < ε_1
                Set leader(Agent 1) to be faulty and be a obstacle
                Choose Agent 2 to be the new leader
                Update follow strategy SBC (A_2, A_3, l_23, φ_23) ,SCC (A_i, A_j, A_k, l_ij, l_ik)
                New leader leads followers to avoid the collision with the agent1.
        else if ε_1 < v_1^k < ε_2
                Update v_i for Agent i (i=2,3,4,5,6)
                else if v_1^k > ε_2
                Choose Agent 2 to be the new leader
                Update follow strategy SBC (A_2, A_3, l_23, φ_23) ,SCC (A_i, A_j, A_k, l_ij, l_ik)
                New leader guides followers to move on
                end if
        end if
        end if
end
%Fault diagnosis and obstacle avoidance of followers
for i=2 to 6
        if 0 ≤ v_i^k < ε_1
                Set Agent i to be faulty and be a obstacle
                if i=2
                Update follow strategy of agent i+1 as SBC (A_1, A_{i+1}, l_{1(i+1)}, φ_{1(i+1)})
        else update follow strategy of agent i+1 as SCC (A_{i+1}, A_j, A_k, l_{(i+1)j}, l_{(i+1)k})
        end if
        Other agent moves on with avoiding agent i
        else if ε_1 < v_i^k < ε_2
        Update v_i for Agent i (i=2,3,4,5,6)
        else if v_i^k > ε_2
                Set Agent i to be faulty and be a obstacle
                if i=2
                Update follow strategy of agent i+1 as SBC (A_1, A_{i+1}, l_{1(i+1)}, φ_{1(i+1)})
                else update follow strategy of agent i+1 as SCC (A_{i+1}, A_j, A_k, l_{(i+1)j}, l_{(i+1)k})
                end if
        Other agent moves on with avoiding agent i
        end if
        end if
        end if
end
```

5 Simulation and results

The simulation model of 6 amigo mobile robots is prepared using the Matlab/Simulink environment. Each robot is regarded as an agent. It is assumed that the multi robots move with uniform velocity. Under normal condition, the multi robots in the flocking can move with uniform velocity until reaching the destination. Considering two flocking motion modes, one is linear motion, the other is linear motion with 45 degrees. The desired trajectory is shown in Figure 4.

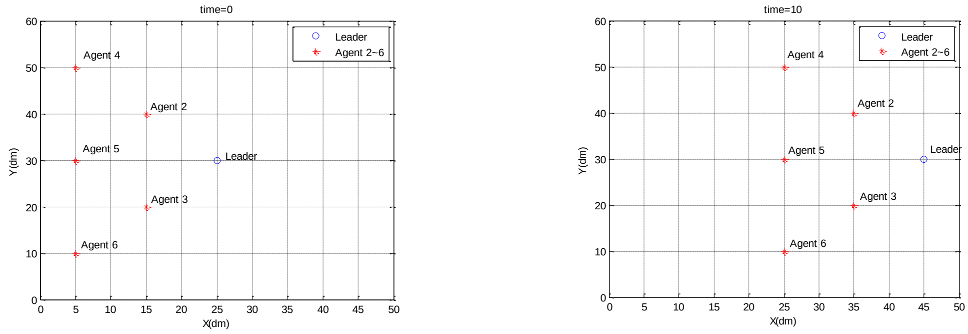


a) linear motion of flocking b) linear motion with 45 degrees of flocking

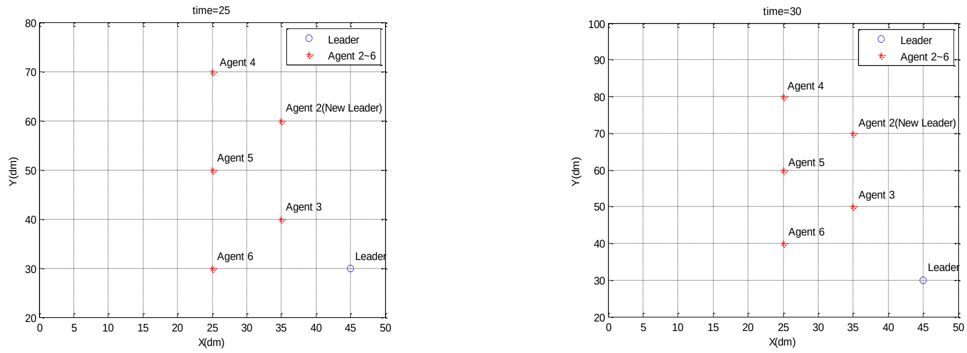
FIGURE 4 The desired trajectory of the motion of flocking

5.1 SIMULATION EXPERIMENT 1: LEADER FAULT

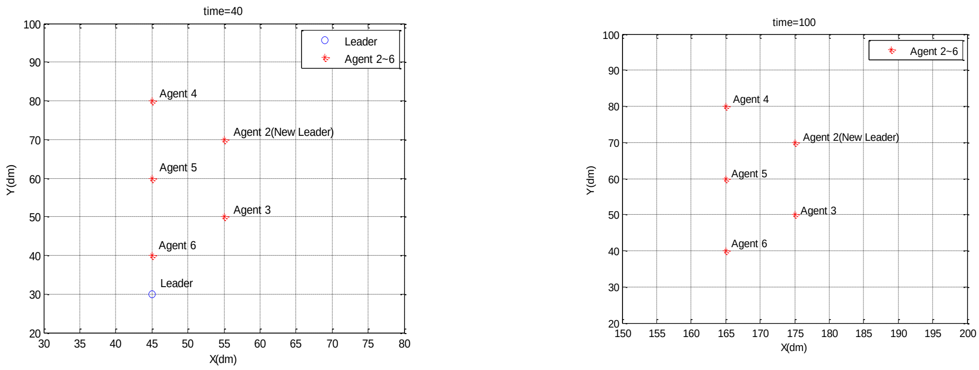
The original positions of A1~A6 are [25,30], [15,40], [15,20], [5,50], [5,30], [5,10]. The target of the motion of flocking is to move 100s. Leader is set to stop at *t*=10s. According to the fault agent diagnosis and avoidance algorithm shown in Table 1, Agent 2 is set to be new leader to guide other agents. The obstacle avoidance of flocking is shown in Figure 5.



a) Original position when *t*=0s b) Leader is faulty when *t*=10s



c) Agent 2 lead the motion of flocking when *t*=25s d) Locations of all the agents when *t*=30s



e) Locations of all the agents when t=40s f) Locations of all the agents when *t*=100s

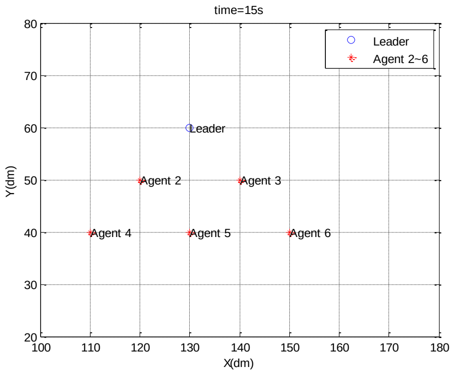
FIGURE 5 The motion of flocking with fault leader

As shown in Figure 5a shows the original position of 6 Agents. In Figure 5b, the location of the leader being faulty is marked at the time of t = 10s. The failure is simulated through setting the velocity of leader as zero. In Figures 5c and 5d, the location of other agents are marked when t = 25s and t = 30s respectively. Detecting the fault leader, Agent 2~Agent 6 choose Agent 2 as the new leader. And the new leader will guide other agents to avoid the fault leader. Figures 5e and 5f present the location of Agent 2~Agent 6. The results shows that the flocking of multi-agent can re-choose new leader quickly, and can continue the motion with avoiding the fault leader under the guidance of new leader.

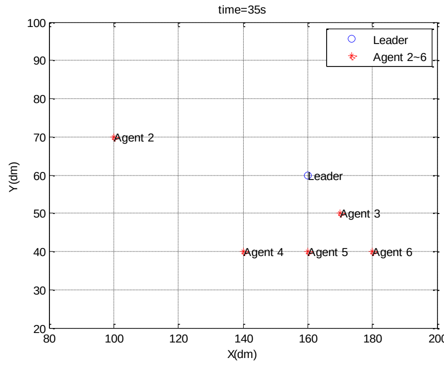
5.2 SIMULATION EXPERIMENT 2: AGENT 2 FAULT

In this experiment, the flocking moves along a linear motion with 45 degrees. The normal motion trajectory is shown in Figure 4b. The original positions of Agent1 to Agent 6 are [160, 30], [150, 40], [170, 20], [140, 50], [160, 30], [180, 10]. The requirement of flocking is that leader should turn at the position of Y=130 and move along a diagonal direction, until to the position of X=160.

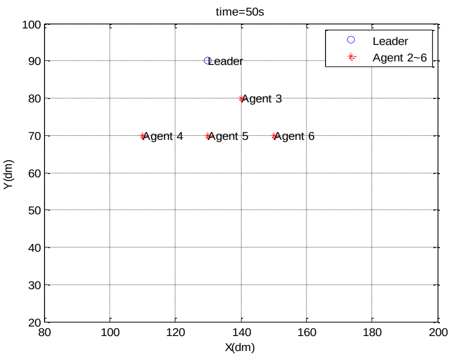
Agent 2 is set to be faulty when t=15s. Its velocity decreases. The results of avoidance of Agent 2 are shown in Figure 6.



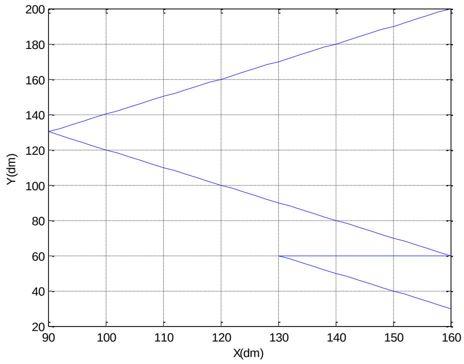
a) The locations of all agents when t=15s



b) The locations of all agents when t = 35s



c) The locations of all agents when t=50s



d) The whole trajectory of the leader

FIGURE 6 The motion of flocking with fault agent 2

Figure 6 shows that the flocking avoids the Agent 2 successfully and accomplishes the task. In Figure 6a, the location of the Agent 2 being faulty is marked when t = 15s. The speed of Agent 2 is assumed to be 1 dm/s in the experiment. Figure 6b shows the locations of all agents when t = 35s. Additionally, the agents successfully avoid the malfunction agent and start to move along a diagonal direction. Figure 6c shows the locations when t = 50s. Figure 6d presents the whole trajectory of the leader. It shows that when t = 15s, the leader is at the location of [130, 60]. At the same time, Agent 2 becomes faulty. The leader cannot move along the diagonal direction, as Agent 5 will collide with Agent 2. As a result, the leader starts to modify the motion direction to avoid the obstacles, and will not resume their original diagonal-direction motion until the completion of the obstacle avoidance.

6 Conclusions

In this paper, we introduced the motion of flocking of multi-agent with a leader. According to the velocity of agent, we classified the fault agent into six types, three for leader and three for follower agents. The fault agent diagnosis and avoidance is implemented by the method proposed in this paper. The simulation results confirm that the proposed method has good fault diagnosis and obstacle avoidance effect.

In reality, more agents will be faulty and more complicated fault types will occur in the motion of flocking. We plan to further investigate more fault types in flocking of multi-agent. Also we plan to study different algorithm to improve the fault agent avoidance efficiency.

Acknowledgments

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