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Control of flock behavior by using tau-margin -Obstacle avoidance and reformation-

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Abstract: In this paper, we address the control of flock behavior using the time to contact called the tau-margin. Recently, swarm intelligence has attracted considerable attention, and it has been applied to control various agents. The Boid theory proposed by Craig Reynolds (1987) is one such application. In ecological psychology, it is considered that animals perceive the time to contact with an object, instead of the distance to the object. In this study, we developed a simulator that simulates the dynamics of mobile agents and their visual system. We embedded modified Boid rules in which the tau-margin is considered instead of the distance. Our simulation results show the realization of flock behavior. In addition, we observe separation to avoid obstacles and reformation to pass through a narrow space.

Keywords: tau-margin, boid, flock behavior

1 INTRODUCTION

Recently, swarm intelligence has attracted considerable attention, and it has been applied to control various agents [1-7].

The Boid theory proposed by Craig Reynolds [1] is one such application. In this theory, we can simulate flock behavior by using three simple rules: separation, alignment, and cohesion. Therefore, the Boid theory was used in various conventional areas.

However, Boids are significantly different from real creatures. Thus, we cannot explain the mechanism of flock behavior of real creatures by using this theory. The difference lies in the information utilized for realizing flock behavior. In the Boid theory, information about the distances among agents is employed. However, most animals have no distance sensor and hence cannot perceive precise distance. Thus, most animals cannot utilize the rules of Boid.

On the other hand, in ecological psychology, it is considered that animals perceive the time to contact with an object, instead of the distance to the object [8]. This time to contact is called the tau-margin and is obtained from the apparent size of the object and its temporal change.

In our previous work, we assumed that the flock behavior of animals was realized by using the tau-margin. Moreover, we tried to realize flock behavior using the tau-margin instead of the distance [9]. However, there were no obstacles and the size of all the agents was the same. Therefore, the discussion on the validity of control using the tau-margin was restricted.

In this paper, we propose modified Boid rules in which the tau-margin is employed instead of the distance. We discuss the validity and effectiveness of this method by using obstacles and many agents whose sizes are different from each other.

2 TAU-MARGIN

In ecological psychology, it is considered that animals perceive the time to contact with an object, instead of the distance to the object. This time to contact is called the tau-margin. Fig. 1 shows the tau-margin when an object is approaching.

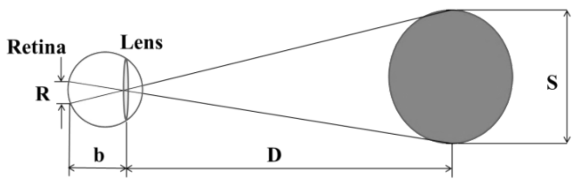

Fig. 1. Tau-margin

S is the diameter of the object, and D is the distance from the object to the crystalline lens. The distance from the crystalline lens to the retina is b.

In this case, the diameter of the retinal image of the object, R, is given by equation (1).

$$R = \frac{bS}{D} \tag{1}$$

By differentiating equation (1), we obtain equation (2).

$$\frac{d}{dt}R = \dot{R} = -\frac{bS}{D^2}\dot{D} \tag{2}$$

From equations (1) and (2), tau-margin τ is given by equation (3)

$$\frac{R}{\dot{R}} = \frac{\frac{bS}{D}}{-\frac{bS}{D^2}\dot{D}} = -\frac{D}{\dot{D}} = \tau \tag{3}$$

Equation (3) indicates that the time to contact $D/\dot{D}$ can be determined from the apparent size and its temporal change. In other words, the tau-margin is obtained from visual information instead of distance information.

3 FLOCK BEHAVIOR

In this section, we realize flock behavior by applying modified Boid rules using the tau-margin.

3.1 Model

We employ agents moving on the horizontal $x-y$ plane. To simulate the movement of the agents, we employ equation (4).

$$m\frac{d^2\mathbf{x}(t)}{dt^2} + C\frac{d\mathbf{x}(t)}{dt} = \mathbf{F} \tag{4}$$

m is the mass of an agent, and $\mathbf{x}$ is a position vector in the $x-y$ plane. C is the air resistance coefficient. $\mathbf{F}$ is the impellent force of the agent.

3.2 Modified Boid rules

We modify the conventional Boid rules by using the tau-margin instead of the distance. Boid theory consists of the three rules of separation, alignment, and cohesion. The modified rules are as follows:

<Separation>

Implement force to separate is given by equations (5) and (6), such that

$$F_x = -\cos\theta \cdot Kp \cdot \frac{1}{\tau} \tag{5}$$

$$F_y = -\sin\theta \cdot Kp \cdot \frac{1}{\tau} \tag{6}$$

where Kp is the proportional gain. F_x and F_y are impellent forces in the x and y directions, respectively. τ is the minimum tau-margin among neighboring objects. θ is the angle to the object that has the minimum tau-margin from the *x* axis, as shown in Fig. 2 (anticlockwise is positive).

When an object approaches the agent, τ converges to 0. Therefore, the implement force to avoid collision is generated by equations (5) and (6).

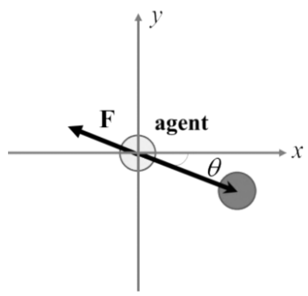

Fig. 2. Separation

<Alignment>

Implement force for alignment is given by equations (7) and (8).

$$F_x = -\cos\theta \cdot Kp \cdot \tau \tag{7}$$

$$F_y = -\sin\theta \cdot Kp \cdot \tau \tag{8}$$

When a neighbor object moves away from the agent, τ of the object has a negative value. Therefore, the behavior to follow the object is realized, as shown in Fig. 3.

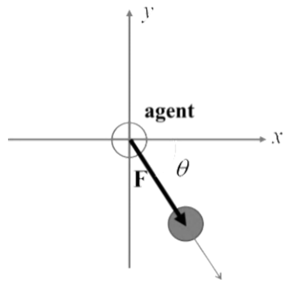

Fig. 3. Alignment

< Cohesion>

Implement force for cohesion is given by equation (9) and (10).

$$F_x = \cos\varphi \cdot Fc \tag{9}$$

$$F_y = \sin\varphi \cdot Fc \tag{10}$$

Fc is a positive constant. φ is an angle to the center of gravity of the apparent size of visible objects, as shown in Fig. 4. From equations (9) and (10), it can be found that the agent moves to the center of the flock by a constant force.

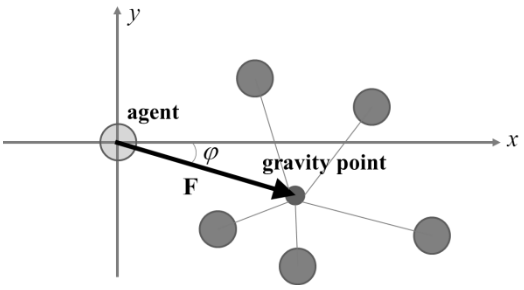

Fig. 4. Cohesion

<Selection of rule>

In the conventional Boid theory, a suitable rule is selected from separation, alignment, and cohesion, on the basis of distance. In contrast, in this study, we select a suitable rule on the basis of the tau-margin, details of which are provided in section 4.

4 SIMULATION

We employ one circular leader agent and nine circular follower agents. The leader agent has a radius of 0.5 m, and the followers' body size is set at random, with a radius within the range from 0.3 m to 2.5 m. Each agent has one eye, and its view angle ranges from -135° to +135°. The distance from the crystalline lens to the retina is 0.02 m. The mass of each body is 5 kg. The air resistance coefficient is $C = 1.8 \times 10^{-5}$. The proportional gain is 50, and Fc is 30.

In case of $0 < \tau \le 5$, the rule for separation, in case of $-30 < \tau \le 0$, the rule for alignment, and, in other cases, the rule for cohesion are selected.

4.1 Task 1: Avoiding an obstacle

4.1.1 Outline of simulation

We set agents on the left side of the field, a leader robot on the right side of the agents, and an obstacle (2.5m in radius) on the right of the leader robot. The task of the leader robot is to move to the right, avoiding the obstacle. The implement force of leader robot is applied to move to the right. The rule of separation is the only one employed; the rules of alignment and cohesion are not used. The other agents follow the leader by using modified Boid rules.

In this simulation, an agent is not aware of the positions and the actual sizes of the other agents; moreover, it cannot distinguish between the agents and the obstacles. Only the apparent size and its temporal change are employed for determining the tau-margin.

4.1.2 Simulation result

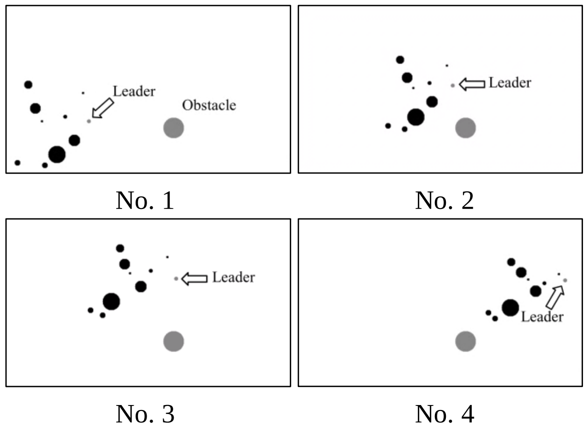

Fig. 5. Task 1

Fig. 5 shows the simulation result of Task 1. When the obstacle approaches the leader agent, the leader avoids the obstacle. Then, the follower agents follow the leader, avoiding collisions.

4.2 Task 2: Passing through narrow space

4.2.1 Outline of simulation

We set follower agents on the left side of the field, a leader agent on the right side of the other agents, and two obstacles on the right of the leader robot. The task of the leader robot is to move to the right. In this case, the leader robot does not have to avoid the obstacles. It can pass through the space between the obstacles. However, the space is so narrow that the flock should change its formation to pass through the space.

4.2.2 Simulation result

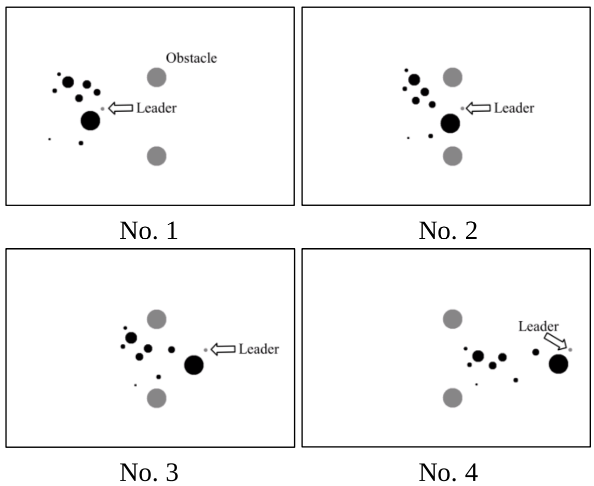

Fig. 6. Task 2

Fig. 6 shows the simulation result of Task 2. From the result, we observe that agents can pass through the space by changing their formation. In addition, we also find that they can avoid collisions with each other in spite of the fact that they are not aware of the distances between themselves.

4.3 Task 3: Avoiding obstacles and passing through narrow space

4.3.1 Outline of simulation

Task 3 is a combination of Task 1 and Task 2. We employ three obstacles, and the leader robot moves to the right, avoiding the obstacles. In this case, the movement of the leader agent is not straight and the other agents have to follow the leader, avoiding the obstacles.

4.3.2 Simulation result

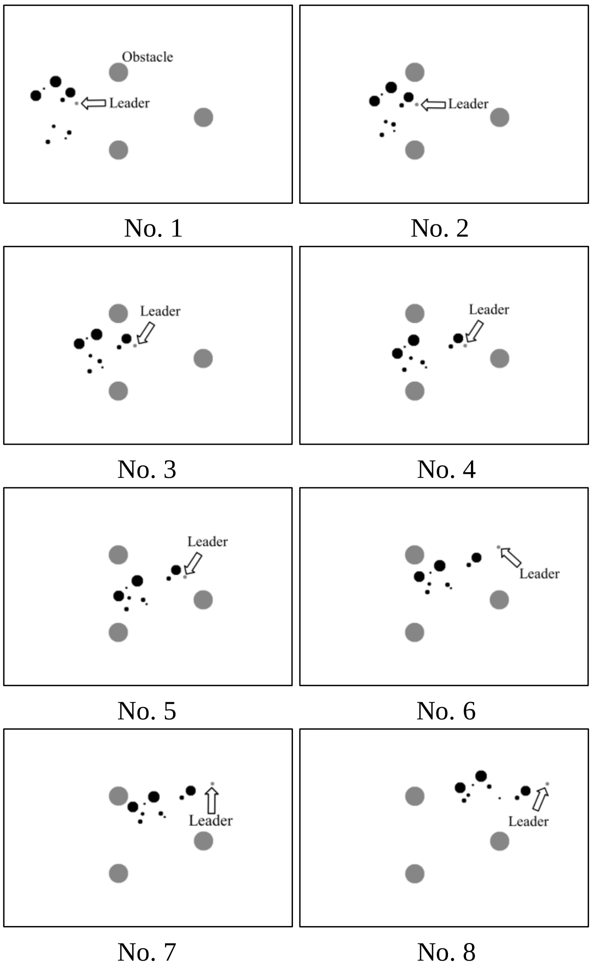

Fig. 7. Task 3

Fig. 7 shows the simulation result of Task 3. We observe that the rules of separation, alignment, and cohesion are suitably selected, and flock behavior to follow the leader agent, avoiding collisions, is realized.

5 CONCLUSION

In this paper, we addressed control of a flock behavior using the time to contact called the tau-margin. We proposed modified Boid rules in which the tau-margin is employed instead of the distance. To discuss the effectiveness of the modified Boid rules, we conducted simulations. From the simulation results, we confirmed that in all cases, agents avoid collisions and follow the leader agent without distance information.

We can conclude that flock behavior can be realized by using only the tau-margin that is obtained from visual information.

ACKNOWLEDGMENT

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