Adaptive Leader Selection based on Influential Individuals

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ABSTRACT
As the development of technology, the demand of operating UAVs (Unmanned Aerial Vehicle) in group grows larger. In the operation of group UAVs, it is important that who the leaders should be and who the followers will be. We use multi-agent technique for this problem. This study proposes the mechanism of leader selection based on influence of an agent to its neighbor's movements. The influence value can be calculated by the forces of neighborhood agents. In the proposed method, the leaders are selected dynamically and adaptively. Simple computer simulation shows the effectiveness of the method.

Categories and Subject Descriptors
I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence

General Terms
Control

Keywords
UAV, Boids, Leader Selection, Complex Systems

1. INTRODUCTION
Technology of UAV (Unmanned Aerial Vehicle) has been evolving rapidly. Several UAVs were used as surveillance tools in conflict region or disaster site[1][2]. Military forces or governments operated these UAVs. Nowadays, however, the demand of commercial use of UAV is the driving force of the evolution. Some companies sell UAV for the tool of airborne imagery. Some companies plan to delivery parcels by UAV.

By the recent development of technology, many commercialized multi-rotor typed UAV has autonomous attitude control system. Manipulation of this type of UAV is quite easy[3][4]. Unlike manipulating radio control helicopter, people don't have to practice to manipulate them. In accord with these facts, we can say that operating single UAV is already in practical stage. So the next challange is operating multiple UAV. The demand of controlling multiple UAVs must be larger when the size and price of the UAV become smaller and cheaper.

This study proposes the simple but effective operating method of multiple UAVs by controlling only a few UAVs in the population. This method can reduce a burden of complex manipulation of multiple UAV. For example, the method may reduce the number of operators. In this method, the most effective UAV in a flock can be selected as a leader, and the other UAVs become followers.

2. LEADER SELECTION BASED ON INFLUENTIAL INDIVIDUALS
Several rule-based models are proposed to illustrate the flocking behavior of birds or fish[5][6][7]. In this section, we proposed the dynamic leader selection which is combined the concept of boid and the concept of influential individuals[14][15].

2.1 Boids
Boids are developed by Reynolds in 1986[6]. This simulates the flocking behavior of birds. Boids can produce flocking behavior obeying the following three rules.

- **Cohesion:** This rule steers a boid to move toward the center of mass of neighboring boids. The force of cohesion can be written as:

$$F_c = \frac{\sum_{j \in dist(i,j) \leq r_c} x_j}{\sum_{j \in dist(i,j) \leq r_c} 1} - x_i \quad (1)$$

- **Separation:** This rule steers a boid to avoid crowding neighboring boids. The force of separation can be written as:

$$F_s = \sum_{j \in dist(i,j) \leq r_s} (x_i - x_j) \quad (2)$$

- **Alignment:** This rule steers a boid towards the average direction of neighboring boids. The force of alligment can be written as:

$$F_a = \frac{\sum_{j \in dist(i,j) \leq r_a} v_j}{\sum_{j \in dist(i,j) \leq r_a} 1} - v_i \quad (3)$$

BICT 2015, December 03-05, New York City, United States

DOI 10.4108/eai.3-12-2015.2262513

Here, $d(i,j)$ is a distance from boid i to boid j. r_c, r_s, and r_a are range of the forces. Therefore, the force of flocking is the sum of these forces:

$$F_{flock} = c_c F_c + c_s F_s + c_a F_a \quad (4)$$

where, c_c, c_s, and c_a are constants.

2.2 Leader Selection

There are several approach to introduce a mission into boid [9] [10] [11] [12] [13]. Here, we pick up simple and effective approach: Leader and Follower approach. In this approach, small number of the boid will be leaders who want to achieve the mission and the rest of them are followers who' interest is maintaining a flock. Sato et. al. proposed the dynamic and adaptive leader selection based on the influence of an individual boid to its neighbors[15]. Influential index of boid i is calculated by the following equation:

$$I_i = c_i \frac{\sum_{j \in dist(i,j) \leq r_i} |\dot{\overline{v_j}}|}{|\dot{v_i}|} \quad (5)$$

where, c_i is a constant, r_i is a range of the force. In [15], top a percent boids are selected as leaders and the rest of them are followers. This value a is fixed during the mission.

Deciding top a percent is a drawback of this method, because this calculation needs global information. It may cancel the strong point of the boid — autonomous and distributed control. In that sense, we call this method as "global leader selection based on the influence".

In this paper, we propose an refinement of the leader selection called "local leader selection based on the influence". In this method, each boid has a leadership value. After the comparing the influence value with its neighbors, if its influence value is more than the average of it from the neighbors, the leadership value become larger and vice versa.

We can calculate the average of the influence value as the following equation:

$$\overline{I_i} = \frac{\sum_{j \in dist(i,j) \leq r_i} I_j}{\sum_{j \in dist(i,j) \leq r_i} 1} \quad (6)$$

Therefore, the update rule of the velocity of the boid i is as follows:

1. calculate I_i and $\overline{I_i}$
2. if $I_i > \overline{I_i}$ $\alpha = \alpha + \triangle$. If $\alpha > 1.0$, $\alpha = 1.0$
3. if $I_i < \overline{I_i}$ $\alpha = \alpha - \triangle$. If $\alpha < 0.0$, $\alpha = 0.0$
4. $v_i(t+1) = v_i(t) + (1-\alpha)F_{flock} + \alpha I_i$

where, $\triangle$ is update value. Initial value of α is 0.5.

3. COMPUTER SIMULATION

In this section, we examine the effectiveness of our proposed method. The scenario of the simulation is as follows: the mission of the boids is to reach the target without collapsing flock. An initial state of this situation is shown in Fig. 1. The position and the velocity of each boid are set randomly. We compare our proposed method – local leader selection based on the influence – with other types of leader selection methods: global leader selection based on influence and random leader selection.

Figure 1: Initial configuration of the problem. The purpose of boids (triangle) is to chase a target (circle) without collapsing flock.

From Fig. 2, the local leader selection shows the best performance. Fig. 3 shows the number of leaders in a flock. In the beginning, there are large number of leaders (Fig. 4), however, when the movement of the flock becomes stable, the number of leader decrease (Fig. 5. This shows the adaptability of the proposed local leader selection method.

4. CONCLUSIONS

Owing to the development of multi-rotor technology, it becomes easy to manipulate single UAV because it can fly almost autonomously. Recently, the size of UAV is getting smaller and the price is getting cheaper, therefore, there must be a situation where we have to deal with many UAVs at the same time. For this purpose, we proposed the simple and effective control mechanism based on the influence of an individual to its neighbors. Simple computer simulation shows the small number of leaders can take the whole flock of boids to the demanding place. Theoretical explanation and applying the method to more complex situation are our future work.

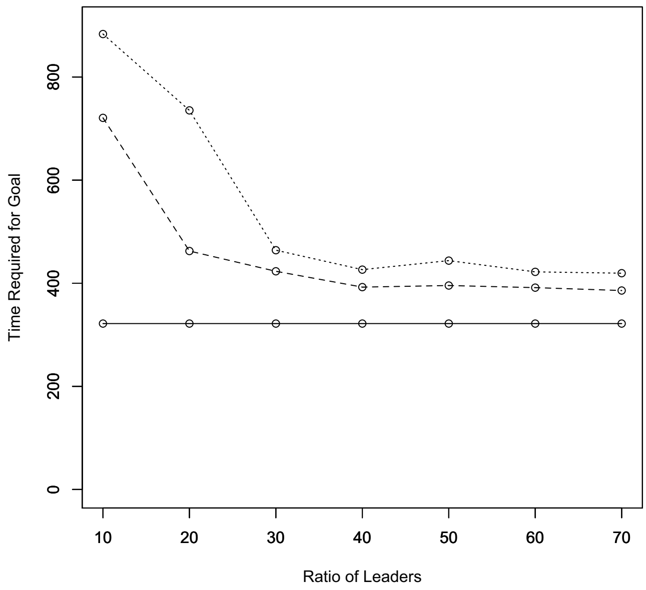

Figure 2: The time required to reach the target. Solid line: Local leader selection, Dashed line: Global leader selection, Dotted Line: Random leader selection.

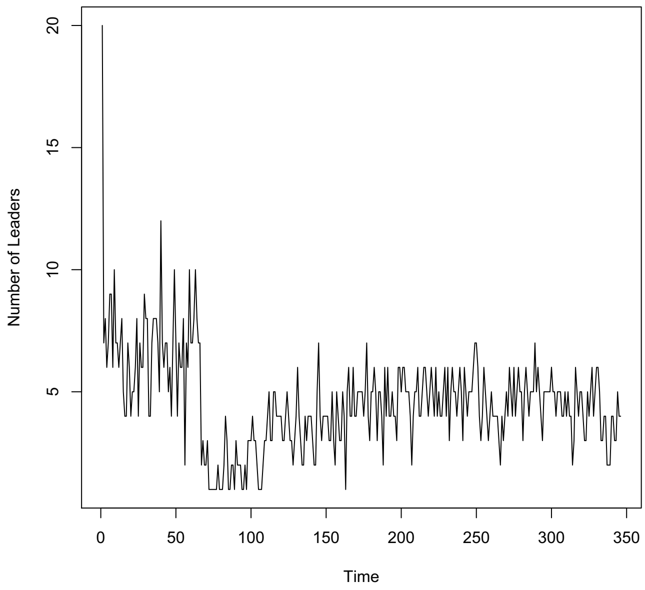

Figure 3: The time evolution of the number of leaders in boids.

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Figure 4: Beginning of the simulation: The flock is unstable. There are many leaders in a flock and the direction of movement is not decided yet. Red: leadership value $\alpha \geq 0.5 (= leader)$, Blue: leadership value $\alpha < 0.5$ (follower), Link: interaction between boids

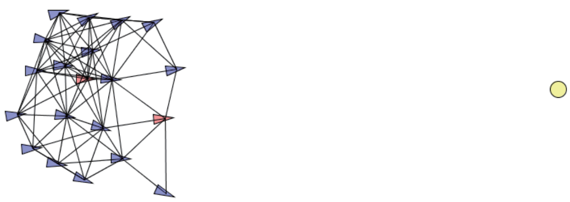

Figure 5: Last stage of the situation: The flock is stable. After the consensus of the direction of movement, the number of leaders becomes small. Red: leadership value $\alpha \geq 0.5 (= leader)$, Blue: leadership value $\alpha < 0.5$ (follower), Link: interaction between boids