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Unmanned aerial systems coordinate target allocation based on wolf behaviors

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Unmanned aerial systems (UASs), especially the cluster of UAS, are highly focused and widely used in various domains. The application of small and inexpensive UAS with a large-scale group to perform complex tasks has become a mainstream trend. Thus, collaborative task assignment of UAS has become a problem that must be solved. UAS cluster flight is similar with the social behavior of wolves.

The wolf, one of the most cunning and cruel predator, is endowed with excellent hunting skills during the long-term evolution. Researchers and engineers try to create an innovative biomimetic task assignment mechanism. And the biomimetic task assignment mechanism could replace traditional task assignment mechanism for UAS. Researchers and engineers use multiple agents by setting some rules to simulate wolves collaborative hunting. Muro et al. [1] used a simulative experiment to simulate wolves chasing behaviors surrounding a single prey. Madden et al. [2] used multi-robot to simulate a wolf group to hunt for prey and verify it in a laboratory environment. In this study, a wolves' labor division mechanism is proposed. This mechanism is applied to the target's distribution of UAS, and an experiment was conducted to verify the mechanism with five UASs.

Wolf behavior mechanism. There are complicated hunting rule and process in wolves' hunting [3]. When hunting coordinately, especially when killing large-scale prey that is several times their weight, wolves take turns to attack prey and wear it down. At the beginning of hunting, wolves are going to chase after prey along a trajectory defined by a paw function. A wolf usually chases after prey near the path.

The chief wolf calculates priority of all targets and then sorts them [4]. The targets with the highest priority are prioritized to participate in allocation. This study adopts a paw function distance to measure the priority.

If the coordinate of launch point is $(0,0)$, the paw function is a function set as shown below:

$$P=\left\{(x,y)|y=x\tan\frac{i\pi}{2(N+1)},\ x,y\in\mathbb{R}^{+}\right\}, \tag{1}$$

where N is the quantity of UAS, $i=1,2,\ldots,N$, (x,y) is a coordinate in the curve of paw function. And the paw function distance is denoted as

$$\mathrm{Dis}_{\mathrm{paw}}=k\sqrt{x^2+y^2}+\min\left(\sqrt{(x-x_0)^2+(y-y_0)^2}\right), \tag{2}$$

$$(x_0,y_0)\in P,$$

where k is scale factor. The less the paw function distance is, the higher the priority of the target is. A target will be preassigned to a UAS with the shortest paw function distance.

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During the hunting, a wolf requests assistance to other wolves nearby or responds to other wolf's request. In the assignment of targets, we need to consider the constraints, benefits, and costs of the targets, which are shown below:

$$\text{profit} = \text{dens} + \text{val} \times \sum_{i=1}^{k} \text{harm}_i, \tag{3}$$

$$\text{cost} = \sum_{i=1}^{k} f_i, \tag{4}$$

$$\text{fit} = \text{cost} - \text{profit}, \tag{5}$$

$$k = \text{argmax}(\text{fit}), \tag{6}$$

where profit is the profit of targets, dens is the density of targets. val is the value of targets, and $\sum_{i=1}^{k}\text{harm}_i$ is the harm to the target by UAS. cost is the total cost paid in the task, f_i is the special cost the ith UAS paid in the task. During the task allocation, all UASs receive the information of targets and calculate fit according to their respective status. Then it will be gathered and sorted to pick a UAS with the maximum of fit to attack the target.

The steps of target assignment based on wolf mechanism are shown below:

Step 1. Calculating the priority of targets. At the beginning of the algorithm, there is a necessity to sort targets according to (1) and (2). Then UAS will fly straight to the position of targets by priority.

Step 2. Calculating the fit of targets. During the process of flying towards the target, each UAS calculates the fit of all targets and of all UASs by (3)–(6). And the quantity of UAS requested by the target is calculated by (6). For each target, it will be reassigned to a UAS with the maximal value of fit.

According to the step above, we suppose the time complexity of (2) and (5) once as $O(1)$. Then the time complexity of (3) and (4) is $O(n^2)$, the time complexity of the developed coordinate target allocation scheme is

$$T(n) = O(n^3), \tag{7}$$

where n is the number of targets. Due to the limit of the time complexity, the maximum quantity of UAS is limited as

$$N < \frac{T}{T(n)}, \tag{8}$$

where T is an iterations period of the algorithm. Or we limit the quantity of UAS which involve the target. Then the time complexity will be

$$T(n) = O(n^2). \tag{9}$$

Unmanned aerial system swarm design. UAS has the advantages of zero casualties, high-speed overload, excellent stealth performance, short operational preparation time, relatively low life-cycle cost, which has been developed at a fast speed in recent years. There appears a modern tendency, simple UAS swarm for sophisticated missions instead of a single complex UAS [5]. Especially a close formation flying with rotation would extend the flight range of UAS [6]. We suppose that there are multiple targets, multiple UASs, multiple loads and so on. Under these conditions, the number and the position of targets, the tasks that each UAS is going to perform in order, and the position of launching airport and landing airport is given [7, 8].

During the process of target assignment, each UAS is regarded as a hunting wolf. Each target to be assigned is mapped as a prey. The UAS flying towards the targets is mapped as a wolf chasing prey. The division of labor and cooperation in the process of hunting prey between wolves is mapped as the process in which UAS cooperatively distribute targets. To verify the validity and feasibility of algorithms, we have developed a kind of quadrotor based on the Linux computer which conducts the wolf mechanisms. And its framework is described in Figure 1.

There are several UASs which carry the Linux computer. One of the UASs is shown in Figure 1. They request data from the flight controller board and send a command to the flight controller board by the MavLink protocol in a wired manner. The requested data is on the status of flights such as the global position, the velocity of each UAS in near real-time. The sent command is on the status of UAS which the Linux computer expected such as the target position, the target velocity of each UAS. Between different UASs, they connect to receive and send data on the other UAS' status of fights and task assignment by the user datagram protocol (UDP) wirelessly. Also, the ground station sends the command on automatic take-off and landing, the mode switching by transmission control protocol (TCP).

Experiment. The low-level controller of UAS is a classical cascade PID controller of quadrotors. The wolf mechanism offers the current target to the low-level controller. Then UAS will fly straight to the position of targets. To verify the feasibility and effectiveness of the target allocation based on wolf behavior mechanism, a series of experiments was conducted in outdoor, where five UASs were controlled by a computer underground as the ground station. We defined val = 1, $\text{harm}_i = 1$,

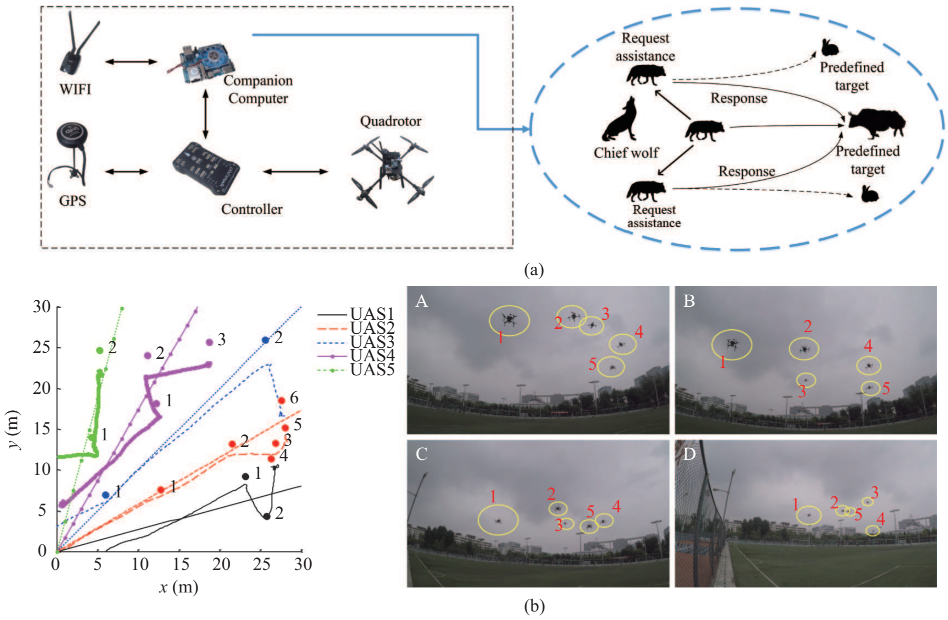

Figure 1 (Color online) (a) Framework of UAS based on wolf behavior mechanism; (b) results of a outdoor flying experiment.

$R = 10$ m, f_i as the distance from the ith target. Details of the experiment are in the video attachments. The result of four UAS is shown in Figure 1.

As shown in Figure 1, the colored dot denotes the virtual target. The curve denotes the real trajectory of UAS. To avoid colliding, we set different altitude for different UAS. According to the results of the outdoor experiments, all UASs reached the virtual targets irrespective of the error of GPS. The snapshots of outdoor experiments are given in Figure 1.

Conclusion. In this article, the target allocation based on the wolf behavior mechanism has been verified. Experimental results demonstrated this method could effectively solve the problem of multi-UAS collaborative target allocation. In the future, we will focus on the target allocation based on more UASs.

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Supporting information Videos and other supplemental documents. The supporting information is available online at info.scichina.com and link.springer.com. The supporting materials are published as submitted, without typesetting or editing. The responsibility for scientific accuracy and content remains entirely with the authors.

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