Organization of unmanned aerial vehicles movement as a group

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Abstract. This paper describes the organization of movement of unmanned aerial vehicles in a swarm based on modification of the potential field method. Collision prevention is carried out by the potential field method, and relatively uniform distribution of agents in the free space is provided by the control system component, which uses the change of the repulsion field radius depending on the number of neighbors and the distance to them. Averaging the value with neighbors is used to reach consensus on the value of the repulsion field radius. In addition, the results of modeling an algorithm demonstrating satisfactory work and low requirements to the speed of information exchange network are given.

1. Introduction
Nowadays, the topic of robot swarm management is gaining popularity [1,2]. Today, there are great success in organizing the movement of quadcopters, even taking into account the air flows created by each drone. One of the common solutions to the problem of UAV positioning in the system is the potential field method [3–5], the master-slave method [6–10], the swarm intelligence method [11] (in this paper it is something average between the methods of potential field and master-slave), and the local voting method [12,13]. Binary tree elements can be used to form the structure of the UAV [14]. Other algorithms can be used to UAV formation control [15].

However, the local voting method requires quite a large bandwidth of the information interaction network [16], which can be critical with dozens of agents. The potential field method has some problems with agent distribution in a given space. If the radius of agent repulsion fields is constant and the swarm size increases, oscillations may occur in the group caused by too fast periodic change of the agent repulsion force vector and low data exchange frequency. In this case, the closer the agents are to each other, the higher the network load. The proposed report is devoted to the description of a method of organization of swarm agents movement by a modified method of potential field, which allows to solve the above mentioned problems.

2. Task setting
In this paper, an agent is understood as an unmanned aerial vehicle (UAV) of the ATV type in a group capable of information interaction. The following tasks must be solved to organize the movement of an agent in a swarm:

- Create a method of UAV movement as part of a swarm with low network bandwidth to provide:
  - Collision prevention;
  - Distribution of group agents in a given space;
- Perform simulation of the obtained method to verify its operability.

The task should be solved under the following conditions:
• The number of swarm elements is unknown in advance and may change over time;
• Swarm is assumed to be homogeneous, consisting of low-mass quadrocopters (which, unlike aircraft, simplifies the movement of the device on all linear coordinates);
• The turbulence created by propeller groups of ATVs is not taken into account;
• The coordinates of an agent in space are determined without interference.

There are an agents \( N = \{1,2,...,n\} \). The potential field method with some changes is used to organize agent interaction. In this case, the potential field method calculates the position of the virtual leader of each actor the UAV is aiming at. Each agent has an internal state – the radius used to calculate the virtual leader position. Two agents interact with each other if the sum of their radii is greater than the distance between them:

\[
R_1 + R_2 \geq D
\]  

(1)

where \( D \) – distance between agents.

Each agent has neighbors \( N_j = \{1,2,...,j\} \). The resulting direction vector that takes into account neighbors' positions is calculated as follows:

\[
\hat{V}_N = k \sum_j \left( R + R_j - D_j \right) \hat{d}_j,
\]

(2)

where \( k \) – certain tilt coefficient, \( R \) – own radius, \( R_j \) – neighbor radius, \( D \) – distance between agents, \( \hat{d}_j \) – direction vector from neighbor.

The allowed (specified) area will be called the area beyond which the UAV should not be located. The pushback from the allowed area boundary is calculated in the following way:

\[
\hat{V}_h = \sum_i \frac{D_i \|\hat{V}_N\| \hat{d}_s}{R},
\]

(3)

where \( D_i \) – value, inverse distance from agent to surface of permissible area, \( \hat{d}_s \) – direction vector from the surface of the tolerance area.

The cumulative effect that is the sum of the right parts of equations (2) and (3) is defined as:

\[
\hat{V} = \begin{cases} 
V_{max} \hat{d}, & \text{if } \|\hat{V}_N + \hat{V}_h\| < V_{max} \\
\hat{V}_N + \hat{V}_h, & \text{otherwise}
\end{cases}
\]

(4)

where \( V_{max} \) – maximum distance of the virtual leader from the agent, \( \hat{d} \) – total vector direction \( \hat{V}_N + \hat{V}_h \).

This solution allows the UAV without hesitation of the virtual leader's position to approach the border and not to cross it.

Correction of the agent described in the 4th order modeling by angular and linear positions is performed by PID regulators.

The problem of uneven distribution of swarm agents in a given space at too small an agent's field radius as well as the problem of oscillations at too large is solved by adjusting the field radius value. Let there be an area of space allowed for the agents to fly, then there will be such a radius of field of an agent that all the UAVs will be distributed in this area relatively evenly and so that the neighbors' influence will not cause oscillations.
It is necessary to introduce the notion of agent pressure, which is the ratio of the resulting virtual leader position vector to the number of neighbors, the value of which is determined at each iteration of data exchange as:

\[ p = \left( \sum_s \frac{D_s \| \vec{V}_N \|}{R} + k \sum_j \left( R + R_j - D \right) \right)^s (j + s)^{-1} \] (5)

I will also introduce the notion of normal agent pressure. Since the length of the resulting vector of the virtual leader distance is limited and it is necessary to provide sensitivity to changes in neighbors positions, as well as smooth change of this vector to avoid fluctuations in the system, the value of normal pressure should be chosen as the middle of the range of the virtual leader distance vector length to be changed:

\[ p_n = \frac{V_{\text{max}}}{2} \] (6)

The alignment of own pressure with the normal is due to linear movement of the agent and changes in the radius of the repulsion field.

To avert the field radius of agents in a swarm at each iteration of data exchange, each agent averages its value of the radius with the radii of its neighbors:

\[ R_m = \frac{R + \sum_j R_j}{j + 1} \] (7)

Over time, the swarm reaches a differential consensus on the value of the field radius. This means that the field radius value of all swarm agents is averaged with some accuracy. However, each swarm agent has no information about the swarm composition.

After each iteration of data exchange, the agent increments the radius value based on the difference between its own and normal pressure:

\[ R^{k+1} = R^k + \frac{p_n - p}{p_n R^k} \] (8)

where \( k \) – step of iteration data exchange.

This procedure allows you to compress and increase the geometric "volume" of the swarm depending on a given allowable area.

3. Modelling
Software has been created for modeling the method. The Quadrocopter model for linear motion changes the values of roll, pitch and yaw angles; motors are represented by a gain. The software also allows modeling data transfer between agents via Wi-Fi network, where at each moment of time only one agent performs broadcasting. Time of transmission of one message over the network is 6 ms.

The sphere as the most easily described geometrical figure is specified as the acceptable area. The initial values of the actor field radius are selected randomly and have no effect on the quality of the results obtained. Besides, each agent has a minimum possible field radius determined by the UAV dynamics and its dimensions.

The figure 1 shows the result of modeling the movement of 14 agents. Agents start in a group outside the allowed area. When the allowable area is reached, they start to adjust the radius. Figure R shows the field radius of each agent, m, n - calculation iterations. Step of iteration is 2 ms.
New data were exchanged between agents at a frequency of 2 Hz. As can be seen from the figure 1, the system quickly finds the required field radius and then remains stable. The pressure diagram of each agent looks the same. Termination of cardinal change of agent field radii indicates that the swarm has filled all available area space. Besides, since the field radius is adjusted in such a way that the agent takes into account its closest neighbors, in the process of method functioning the load on the information exchange network is significantly reduced in comparison with the potential field method with a rigidly fixed radius value (figure 2).

Figure 1. Radius variation over time

Figure 2. Load on the information exchange network

Figure 2 Pw shows the number of measurements of network load, where the measurement period is 200 ms, and Bw - network load, %.

It should be noted that this modified method of potential field was tested on the UAV group with the following parameters:
- Data exchange frequency 0.5 Hz;
- The number of the swarm is 200 units.
With the proper minimum distance between agents (chosen on the basis of UAV dynamics and data exchange frequency) the system shows stable operation. Of course, with increasing frequency of data exchange quality of work will increase to some limit, but will increase the load on the network.

4. Discussion
Of course, the use of this method is somewhat limited. For example, an aircraft-type UAV, for which many more suitable algorithms have been developed, has difficulty with a sharp change in direction of motion in contrast to the ATV. Therefore, the aircraft type UAV will need to upgrade the method presented. In addition, this method can be used to form the UAV structure, as well as to provide restructuring with minimizing agent movement, as in the case of the binary tree method.

5. Conclusion
Thus, the method of control organization of a group of unmanned aerial vehicles based on the potential field method is presented. Based on the data obtained, the conclusion is made that this method allows to distribute swarm agents over the entire free space and also reduces the load on the information exchange channel. Further work is aimed at refining the modeling tools in terms of accounting for turbulence created by agents, as well as testing the obtained method on given areas of complex shape.

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