MANAGEMENT OF UAV ENERGY CONSUMPTION MINIMIZATION

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One of the urgent problems of the use of unmanned aerial vehicles (UAVs) is the choice of an energy-saving flight mode. With such flight modes, a large flight range and successful completion of the mission are ensured. Many options for saving energy consumption can be considered and offered. In this paper, in order to minimize energy consumption, it is proposed to optimize the UAV flight path. The choice of the UAV's flight path should be chosen such that the flight would be as smooth as possible, without sharp turns. When conducting experimental UAV flights, when choosing the optimal trajectory, the result of saving energy consumption was achieved up to 20%.

Key words: *unmanned aerial vehicle, energy consumption, optimal trajectory, algorithm, flight path*

1. INTRODUCTION

In recent decades, unmanned aerial vehicles (UAVs) have been widely used in various fields of science, technology, industry, the national economy, as well as in the military field. One of the urgent problems of UAV application is the choice of energy-saving flight mode. This is very important for performing, in particular, reconnaissance missions: with energy-efficient flight trajectories, a greater flight range and more efficient task performance are achieved [Bayramov:2022; Xiang et al. 2020; Dukkanci: 2021; Yong: 2016].

When using UAVs for reconnaissance gathering, one of the key tasks is to plan the path in such a way as to minimize the power consumption of the UAV. Most existing methods usually take the shortest flight distance as the optimal target for planning the optimal path, i.e. it is assumed that the shortest path means the least energy consumption of the UAV. However, it should be taken into account that a change in direction (course) can also consume the energy of the UAV in flight, because any change in the flight course is associated with the acceleration of the UAV. And this, in turn, causes an increase in energy consumption.

Previously, it was believed that when calculating the power consumption of a UAV, only the flight range is taken into account. It was assumed that the shorter the flight distance, the lower the energy consumption. That is, the rectilinear movement contributes to the minimum energy consumption. However, in most cases, when performing a reconnaissance mission, when the UAV examines (photographs) a lot of randomly located objects on the ground, the UAV does not fly in a straight line, but along a very complex trajectory with many changes in the flight course. According to the laws of classical mechanics, even at a constant flight speed $|\vec{V}|=const$, a change in the UAV heading means a change in the flight speed vector.

2. RESULTS AND DISCUSSION

Let consider a change of UAV flight path (figure 1).

Between points *a, b* and *c*, the UAV is flying along a straight line. The course does not change, $|\vec{V}|=const$, the energy consumption is minimal. If the UAV is flying between points *a*, *b* and *c'*, then in this case the course at point *b* changes by the angle θ, and the flight speed during the time Δt changes by

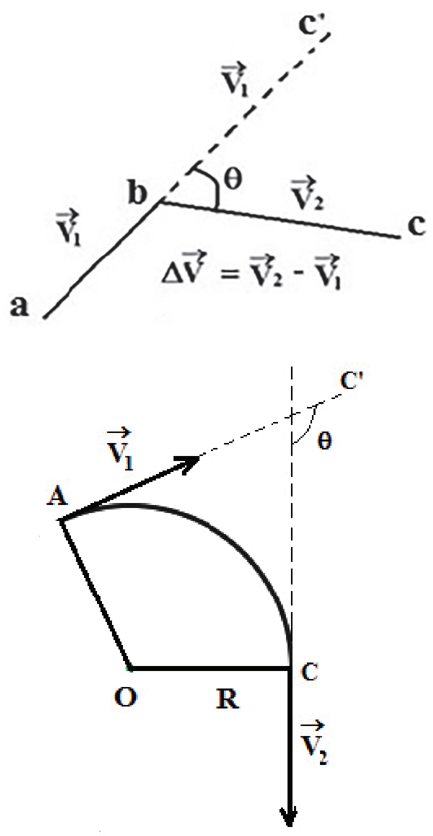

Fig. 1 A change of UAV flight path

$\Delta\vec{V}=\vec{V}_2-\vec{V}_1$. The change in speed per unit time is acceleration: $\frac{\Delta\vec{V}}{\Delta t}=\vec{a}$. With each turn and acceleration, change in the flight course of the UAV, there is an additional consumption of energy. With a smoother change in the UAV flight course, as can be seen from Figure 1, the rotation angle θ becomes small, i.e. a speed change $\Delta\vec{V}=\vec{V}_2-\vec{V}_1$, an acceleration $\vec{a}$, and hence the consumption of additional energy will be less.

The flight of the UAV occurs in two ways (see Figure 1): 1) along a straight trajectory between points *a* and *b*, and 2) along a curved trajectory between points *a* and *c*. Then, in general, the UAV power consumption estimation model can be represented as a function

$$\Delta E_{abc} = G(d_{ab}) + F(r_{bc}),$$

$$(a, b, c = 0,1,\ldots,n;\ a\neq b\neq c)$$

Here, $r=\frac{1}{R}$ is the curvature of the turn, R is the turning radius, ΔE_{abc} denotes the estimated energy consumed by the UAV on the path section $a\longrightarrow c$ when the UAV flies from point *a* to point *c* through point *b*.

The consumed energy includes two components: the energy consumption $G(d_{ab})$ of the UAV in the rectilinear section of the trajectory *ab*, which depends on the distance d_{ab}, and the energy consumption $F(\theta_{bc})$ when the UAV changes its heading in the section of the change in the course *bc*. Energy consumption $F(\theta_{bc})$ depend on the angle θ of course change: the smaller θ, i.e. the smoother the turn of the UAV, the smaller $F(\theta_{bc})$.

In order to minimize of the energy consumption, the UAV flight trajectory should be optimized. It is assumed that the UAV flies at a certain constant altitude. The set of nodes (course change points) consists of the starting point and node points {0, 1, . . ., n} to be flown around. The problem can be abstracted into 0–1 integer programming problem, and a path optimization model can be obtained with the least power consumption of the UAV.

Thus, this paper proposes an energy-efficient method for planning the UAV flight path when performing reconnaissance gathering by modeling the UAV energy consumption. It lies in the fact that when conducting reconnaissance monitoring, the flight path of the UAV should be as smooth as possible without sharp turns.

The simulation result shows that when using the proposed method of the planned path with a smoother trajectory, it is possible to save at least 20% of the power consumption of the UAV for a real flight.

Experimental flights were carried out using a Trimble UX5 HP UAV (see Figure 2) [Trimble] in the absence of wind and during daylight hours. The digital camera «Sony İLCE-7R» was used to photograph objects on the terrain. Flight altitude 125 m. 950 photographs were taken with a resolution of 3-5 cm.

The weight of UAV is 2.9 kg, the dimensions of UAV is 100x65x10.5 cm. Electric motor power of UAV is 1400 W. The UAV used a Trimble Tablet Rugged PC controller. The maximum flight duration of UAV is 40 minutes, the maximum flight of UAV is range 52 km, the maximum speed of UAV is 85 km/h, the maximum UAV flight altitude is 5000 m.

The UAV was launched using a catapult at an angle of 30°. UAV landing angle is 14°. The navigation system L1/L2 GNSS (GPS, Glonass, Beidou, Galileo Ready) was used for control.

The UAV flight route and photographing points are shown in Figure 3. The monitoring (photography) area was 450x5000 m, the distance between the photographing points was 50 m.

Fig.2 Trimble UX5 HP Unmanned Aircraft System

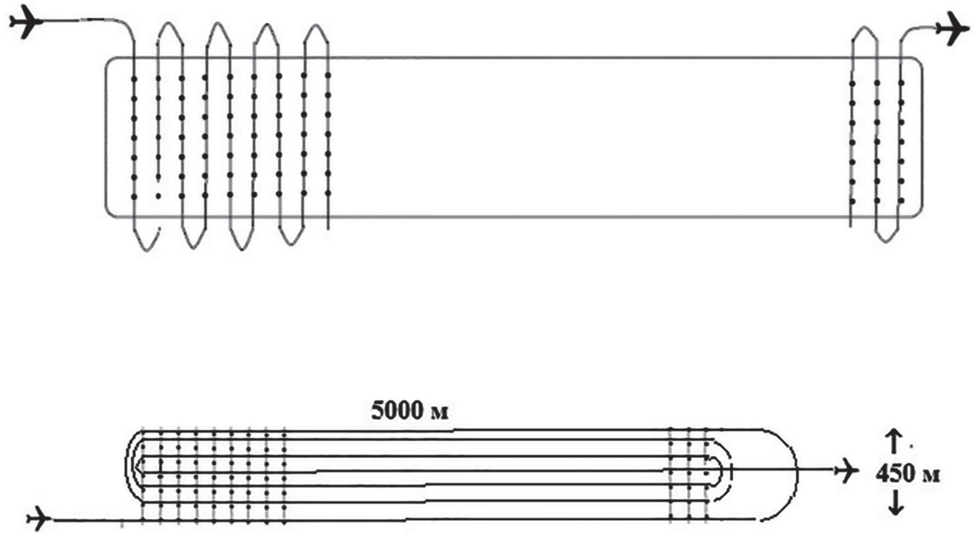

Fig. 3 The patch of UAV and point of shooting

Thus, from Figure 3 it can be seen that 450:50 = 9 lines in width, 5000:50 = 100 UAV flight lines in length.

Flight mode 1: 5000:50=100 x 450 = 45000 m, 50 turns

Flight mode 2: 9 x 5000 = 45,000 m; 9 turns,

In the second mode, energy consumption turned out to be ≈ 20% less.

3. CONCLUSION

Thus, this paper proposes an energy-efficient method for planning the UAV flight path when performing reconnaissance gathering by modeling the UAV energy consumption. It lies in the fact that when conducting reconnaissance monitoring, the flight path of the UAV should be as smooth as possible without sharp turns. Experimental flights were carried out using a Trimble UX5 HP UAV in windless conditions and during daylight hours. The result of the experiments showed that using the proposed path selection method, with a smoother trajectory, it is possible to save up to 20% of the UAV power consumption for a real flight.

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