CONTROL SYSTEMS OF PRIMARY AND ALTERNATIVE POWER SUPPLY SOURCES OF UNMANNED AERIAL VEHICLES

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Summary

The article is devoted to the development of technical possibilities for organizing the energy supply of UAVs. Through the Controlled blocks of the optical system, an issue aimed at identifying and solving possible problems that will occur in the process of power supply of drones due to alternative energy sources and ground-related power sources distributed in different areas was developped. Taking into account the possibilities of power supply distribution and attenuation in the areas where power sources are located, the possibilities of application of UAVs for control of the research object at a stable flight height have been studied and solved. A study of the limiting conditions and threshold values required for the power of signals received from a food source is presented.

Keywords: UAV, Optical system, alternative energy transfer, atmosphere, sources of nutrition.

1. Introduction

At present, the methods of powering UAVs or drones have expanded somewhat and include, in addition to conventional fuel and electric batteries, also energy-saturated laser beams. At the same time, according to [1], the supply of drones in the air with energy can also be carried out using concentrated radio emission at a frequency of 5.8 GHz. For this purpose, drones must be equipped with an antenna and appropriate rectifiers.

According to [2], the efficiency of the laser method of supplying energy to drones largely depends on the correct distribution of the transferred energy between the power unit and command and control units. In this case, the optimization criterion can be the achievement of the maximum flight time.

As noted in [3], the method of supplying drones with energy using a laser beam can be applied in smart city projects, where both high-altitude and low-flying drones are used. At the same time, while high-altitude drones are powered by solar panels, low-flying drones are supplied with energy using laser beams. The effectiveness of such combined power is achieved by optimizing the joint flight of a group of drones at different heights. According to [4], the issues of optimizing the operation of drones powered by a laser beam cannot be reduced to setting convex optimization problems, and the solution to these issues involves taking into account the drone's flight path. As noted in [5], the efficiency of energy delivery to drones by a laser beam largely depends on the degree of focusing of the beam, and the selection of the location of ground recharge stations in the form of the Internet of Things (I0T). It is indicated that the efficiency of the laser method of powering drones can be higher compared to other methods of power supply.

It is noted in [6] that, to drones, a laser beam can perform both the function of guiding and energy delivery. In this case, the power of the laser beam and the photodetector unit must be matched to avoid time losses during recharging.

As noted in [7], the transmission of several kilowatts over distances of several kilometers has already been achieved by the method of laser energy delivery. At the same time, the possibilities of further optimization of energy transfer using a laser beam are far from being exhausted. This article discusses the possibilities of optimizing the energy transfer of laser beams to drones, taking into account the impact of atmospheric factors. In two versions: (a) laser feeding of drones from the base station; (b) combined use of laser power and solar panels.

2. Suggested method

2.1. Powering a drone using a laser

According to [8], the power of the laser beam at the input of the photo- receiving node of the drone is defined as

$$P_{in} = \frac{3{,}44P\,exp\,(-\varepsilon L)}{\pi L^2 \sigma_\Sigma^2 / S}, \tag{1}$$

where: P is the initial power of the laser beam; L is the distance between the laser beam source and the drone; ε-is the attenuation coefficient of the laser beam due to absorption and scattering; σ^2-is the expansion index of the laser beam due to factors such as diffraction, turbulence, thermal effects, etc.; S- is the area of the photodetector.As shown in [8], σ does not depend on the initial beam power P and for the further analysis carried out at a fixed wavelength, expression (1) at

S=const can be represented as

$$P_{in} = \frac{c \cdot P exp\,(-\varepsilon L)}{L^2}, \tag{2}$$

where: $c = \frac{3{,}44 \cdot S}{\pi \sigma_\Sigma^2} = const.$

It is evident that the beam attenuation factor ε is not a constant value in the conditions of an actual drone flight. The drone can fly in areas of clean or polluted atmospheres. In this case, the indicator ε will be determined by the degree of atmospheric pollution in the zone where laser energy delivery is supposed. Therefore, it is possible to formulate the problem of the optimal choice of the flight zone, where ε will optimally depend on some arguments.

The optimization problem is formulated as follows: how to optimally choose the area for feeding drones with energy in flight, if it is possible to vary the values of P and L. by selecting the appropriate feeding station from a plurality of such stations, united in a distributed network.

Let us assume that the zones of possible laser feeding on the plane (x, y) are combined into a distributed network of laser feeding stations for a group of UAVs flying at different heights (Fig.1). The operation zones of the recharge stations are shown as a set of rectangles with equal dimensions (Δx, Δy, Δz). Each of these rectangles denotes a limited space characterized by the attenuation coefficient of the laser beam $c_i, c_j\ i, j - \overline{1, n};\ c_i \neq c_j;\ i \neq j$.

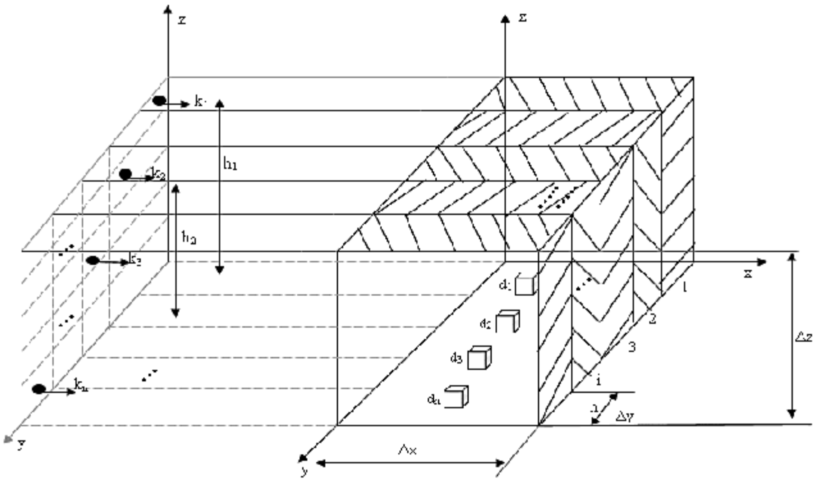

Fig. 1. A distributed network of laser feeding stations for a group of UAVs flying at different altitudes.

The laser feed network serves a set of UAVs, denoted as elements of the set $\{k_i\}$. At the same time, the i- the drone (k_i) lies at a height h_i where $h_{max} \leq \Delta z$. When entering the laser recharge zone, the flight altitude does not change. To recharge the drone k_i enters the rectangle numbered I without changing the flight altitude and being strictly perpendicular above the feeding laser d_i receives at the input of its photodetector the power determined by analogy with (2) in the form

$$P_{int} = \frac{c \cdot P_i \, exp(-\varepsilon h_i)}{h_i^2}. \qquad (3)$$

If we require that all drones receive the same power equal to c_1, we get

$$P_i = \frac{c_1 \cdot h_i \cdot exp(\varepsilon h_i)}{c}. \qquad (4)$$

Next, we introduce the function

$$\varepsilon = \varepsilon(h), \qquad (5)$$

i.e., the drone at height h must be fed in the area where the beam attenuation coefficient is given by (5).

It can be required that the total power $\sum P_i$ be limited to c_0, i.e.

$$\sum_{i=1}^{n} \frac{c_1 \cdot h_i^2 \cdot exp(\varepsilon(h_i) \cdot h_i)}{c} = c_0. \qquad (6)$$

We are also interested in the sum-proposed indicator of the network performance, which characterizes the marginal conditions for carrying out recharge for given h_i.

$$\alpha = \sum_{i=1}^{n} \varepsilon(h_i). \qquad (7)$$

Passing to the continuous notation (6), we express as

$$\int_0^{h_{max}} \frac{c_1 \cdot h^2 \cdot \exp[\varepsilon(h) \cdot h] dh}{c} = c_0. \ (8)$$

Expression (7) is expressed as

$$\alpha = \int_0^{h_{max}} \varepsilon(h) dh. \ (9)$$

Based on (8) and (9), we compose a variational optimization problem for calculating $\varepsilon(h)_{opt}$.

The variational optimization functional F of the type of the neoclassical Lagrange problem is composed in the form

$$F = \int_0^{h_{max}} \varepsilon(h) dh - \lambda \left[\int_0^{h_{max}} \frac{c_1 \cdot h^2 \cdot \exp[\varepsilon(h) \cdot h] dh}{c} - c_0 \right]. \ (10)$$

According to the Euler method, the solution to the optimization problem (10) must satisfy the condition

$$\frac{d\left\{\varepsilon(h) - \frac{\lambda \cdot c_1 \cdot h^2 \cdot \exp[\varepsilon(h) \cdot h]}{c}\right\}}{d\varepsilon(h)} = 0. \qquad (11)$$

From (11) we get

$$1 - \frac{\lambda \cdot c_1 \cdot h^3 \cdot \exp[\varepsilon(h) \cdot h]}{c} = 0. \qquad (12)$$

From (12) we get

$$\exp[\varepsilon(h) \cdot h] = \frac{c}{\lambda c_1^2 \cdot h^3} \qquad (13)$$

or

$$\varepsilon(h) - \frac{1}{n} \cdot \ln \frac{c}{\lambda c_1^2 \cdot h^3}. \qquad (14)$$

Taking into account (14) and (8), we calculate λ.

We have

$$\int_0^{h_{max}} \frac{c_1 h^2}{c} \cdot \frac{c}{\lambda c_1^2 \cdot h^3} dh = c_0. \ (15)$$

From (15) we get

$$\int_0^{h_{max}} \frac{1}{\lambda \cdot c_1 \cdot h} dh = c_0. \qquad (16)$$

From (16) we get

$$\lambda = \frac{1}{c_0 c_1} \cdot \int_0^{h_{max}} \frac{dh}{h}.$$

Taking into account (14) and (17), we obtain

$$\varepsilon(h) = \frac{1}{n} \cdot \ln \frac{c \cdot c_0}{c_1 \cdot h^{n} \int_0^{h_{max}} \frac{dh}{h}}. \qquad (17)$$

Therefore, if there is a restriction of type (8) on the total power of the lasers used, and also under the condition that the altitude of flights fed by the laser is unchanged, subject to condition (17), according to which the UAV flying at a height h must be fed at a station where at a specified altitude the attenuation coefficient is determined by the value determined by expression (17), the most complete activation of recharge stations is possible when the target functional F or the performance indicator of the recharging network (7) reaches a maximum.

1.1. Sharing laser power and solar panels on drones

Consider the option of a joint power supply of drones using laser beams and solar energy. This option is shown schematically in Fig. 2. As can be seen from the diagram presented in Fig. 2.

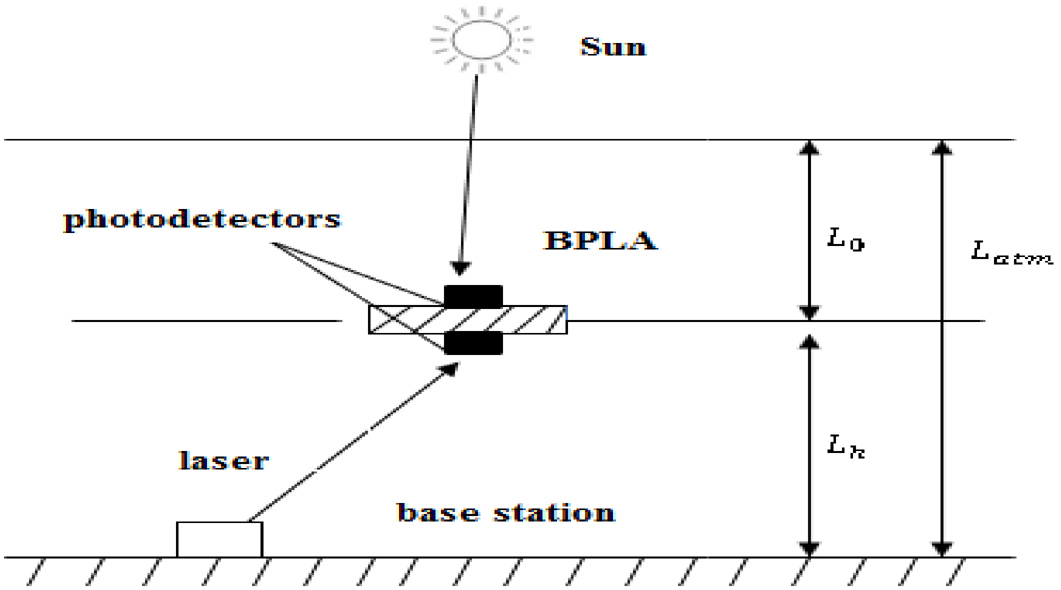

Fig. 2. Schematic representation of UAV power supply using a laser beam and solar energy.

The UAV is powered by two sources, i.e. from the sun and laser radiation. In this case, the UAV is in a position where its upward movement will further weaken the laser beam at the input of the photodetector, but at the same time, the percentage of attenuation of solar energy at the input of the photodetector will increase. Therefore, we can expect the presence of such an optimal height L_{hopt} at which the total attenuation is minimal, and the energy supplied to the UAV is maximum. In contrast to [8], we will consider the case when the UAV power supply occurs in parallel and we should determine the optimal UAV flight altitude, at which the energy loss due to the influence of the atmosphere is minimal.

We estimate the attenuation of solar energy at the input of the solar battery based on the following assumption: We consider that the solar beam is attenuated in the interval L_0, defined as

$L_0 = L_{atm} - L_h$, (18)

where: L_{atm}-эквивалентная толщина атмос is the equivalent thickness of the atmosphere; L_h-UAV flight altitude.

Taking into account (1), the solar radiation power at the input of the upper photodetector is defined a

$P_{sin}(L_0) = P_{c.o} \cdot exp[-mL_0]$, (19)

where: P_0-is the power of solar radiation at the outer boundary of the equivalent atmosphere; m-optical air mass; L_0-is the depth of UAV penetration into the equivalent atmosphere.

At the same time, as L_0 increases, the power of the laser beam P_{Lin} at the input of the lower photodetector increases according to the law

$P_{Lin} = P_{Fa} \cdot exp[-\varepsilon(L_{atm} - L_0)]$, (20)

where: P_{fa}-the initial power of the laser source; ε is the attenuation index of the laser beam due to assistance and scattering.

Let us consider two options for calculating $L_{0.opt}$ at which the total energy at the inputs of the photodetector nodes of the UAV reaches an extremum.

1. Algebraic averaging method
2. Geometric averaging method

In the first case, the total energy $P_{0\Sigma}$ at the UAV inputs is determined as

$P_{0\Sigma} = \alpha_1 \cdot P_{S.0} \cdot exp[-mL_0] + (1 - \alpha_1)P_{fa} \cdot exp[-\varepsilon(L_{atm} - L_0)]$, (21)

where: $\alpha_1 < 1$;

Obviously, at a certain value of L_0 the total energy $P_{0\Sigma}$ must reach an extremum. Therefore, we get the condition:

$$\frac{dP_{0\Sigma}}{dL_0} = 0. \qquad (22)$$

Taking into account condition (22), from (21) we have

$\alpha_1 \cdot P_{c.0}m \cdot exp[-mL_0] = (1 - \alpha_1)P_{fa} \cdot exp[-\varepsilon(L_{atm} - L_0)] \cdot \varepsilon.$ (23)

From (23) we get

$exp[-mL_0 + \varepsilon(L_{atm} - L_0)] = \frac{\varepsilon(1-\alpha_1)}{m \cdot \alpha_1}.$ (24)

From (24) we find:

$$exp[-L_0(m + \varepsilon) + \varepsilon L_{atm}] = \frac{\varepsilon(1-\alpha_1)}{m \cdot \alpha_1} \frac{P_{fa}}{P_{S.0}}. \qquad (25)$$

Logarithmizing (25) we get

$$-L_0(m + \varepsilon) + \varepsilon L_{atm} = \ln\left[\left(\frac{\varepsilon(1-\alpha_1)}{m \cdot \alpha_1}\right)\left(\frac{P_{fa}}{P_{S.0}}\right)\right] \qquad (26)$$

or

$$L_0(m + \varepsilon) - \varepsilon L_{atm} = \ln\left[\left(\frac{m \cdot \alpha_1}{\varepsilon(1-\alpha_1)}\right)\left(\frac{P_{S.0}}{P_{fa}}\right)\right]. \qquad (27)$$

From (27) we find:

$$L_{0_{eks}} = \frac{1}{m+\varepsilon} \ln\left[\left(\frac{m \cdot \alpha_1}{\varepsilon(1-\alpha_1)}\right)\left(\frac{P_{S.0}}{P_{fa}}\right)\right] + \varepsilon L_{atm}. \qquad (28)$$

Thus, when solving (28), the energy at the inputs of the UAV photodetector nodes reaches an extremum.

An analysis of the extremum type (24) is carried out by taking the second derivative with respect to L_0. We have:

$$\frac{d^2 P_{0\Sigma}}{dL_0^2} = \alpha_1 P_{c.0} m^2 exp[-mL_0] + (1 - \alpha_1)P_{fa}\varepsilon^2 exp[-\varepsilon(L_{atm} - L_0)]. \qquad (29)$$

From the condition я $\frac{d^2 P_{0\Sigma}}{dL_0^2} < 0$ we calculate the maximum condition.

$$\frac{\alpha_1}{1-\alpha_1} < \frac{P_{fa}\varepsilon^2 exp[-\varepsilon(L_{atm} - L_0)]}{P_{c.0} m^2 exp[-mL_0]}. \qquad (30)$$

It is obvious that inequality cannot be satisfied, because On the left we always have a positive number, and on the right, we always have a negative number. Therefore, when solving (28), the total energy at the UAV inputs reaches a minimum and the choice of flight altitude at the level $L_{atm} - L_{0_{eks}}$ is the worst from an energy point of view.

1. Conclusions

The problem of optimizing the process of feeding a group of drones flying at different heights at stations of a distributed network of feeding stations containing booster lasers is formulated and solved under conditions of a limitation on the total power of booster lasers. A general indicator of the limiting possibility of laser feeding in such a network is proposed in the form of the sum of the beam attenuation coefficients in the zones of the indicated stations. The procedure for determining the power of feeding lasers, depending on the flight altitude, is determined, at which the proposed overall indicator can reach a maximum. The problem of optimizing the joint use of laser feeding and solar batteries on drones was also formulated and solved.

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