CONTINUOUS MONITORING OF TERRESTRIAL OBJECTS BY MEANS OF DUTY GROUP OF MULTICOPTERS

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Abstract: The paper justifies the idea of continuous monitoring of terrestrial objects by means of multicopters. Multicopters are unmanned aerial vehicles of a special type with the obvious advantages for tasks of monitoring. It is proposed to use a group of multicopters changing each other on duty over the object and a special charging station for their maintenance.

The structure and functioning of the proposed system is described.

Keywords: UAV, multicopter, monitoring, charging station, flight scheduling.

1. INTRODUCTION

Unmanned aerial vehicles (UAV), or drones, find a wide application for monitoring various objects. Commonly tasks of monitoring include data acquisition by measuring some parameters of the object or local zone around it and (or) image acquisition. Information interchanges between an UAV and a control station are provided by a radio channel.

Different tasks require corresponding types of UAVs. For example, it is better to survey extended objects such as terrestrial pipelines or large woodlands by means of unmanned airplanes and vice versa, nonmobile objects of a relatively small size may be monitored by helicopters or multicopters. Such UAVs are able to hover above or near the examined object during a long period of time. Recently especially multicopters [1] have attracted attention due to their definite advantages over other types of drones, such as:

- climbing capacity;
- good weight-carrying ability;
- flight stability;
- ease of control;
- simplicity and reliability of construction.

The typical views of multicopters are shown in Fig.1.

Fig.1. The typical views of multicopters:
1 – quadrocopter; 2 – hexacopter in flight

Being battery powered they are very quiet, extremely manoeuverable and environmentally sound.

As a rule, airborne equipment of a multicopter includes radio transceiver, controller with drivers for brushless motors, gyroscopic flight stabilization system, GPS receiver and various sensors (optionally). If a multicopter is equipped with a video camera, additionally camera rotating mechanism and corresponding controller are necessary. Commonly on-board power source is a battery of lithium-polymer accumulators that can provide typical time of flight about 30 minutes. After that recharging is necessary.

As well as monitoring multicopters can perform other functions, such as delivering small packages, spraying some chemicals above the object, performing the function of retransmitting station for communication with hard-to-reach objects and so on.

But in many cases 30 minutes of flight are not enough for tracking, investigation of an object or other tasks. Often continuous (sometimes twenty-four-hour) monitoring is required. Examples of objects where continuous monitoring is required:

- natural objects with catastrophic evolution (flooded areas, volcanoes and geysers, avalanches and torrents, forest fires and so on);
- industrial constructions under the threat of collapse;
- city thoroughfares with problem traffic.

Among other feasible solutions providing continuous or long-duration flights there is the idea concerning application of a powerful laser beam that could be directed from the ground to the UAV permanently delivering wireless energy. Such technology was realized and a series of successful experimental flights of laser-powered UAVs were demonstrated [2]. A ground laser station contains arrays of near infrared laser diodes and focusing device. The laser beam is captured and focused onto a photovoltaic panel by a series of mirrors allocated on the UAV's board. Recharging scenario is nonstop: An UAV could be "refueled" simply by entering a five-mile charge radius for a few hours without landing.

However today the described laser systems have the obvious disadvantage: The transfer of power from source to craft is extremely inefficient. This could be particularly problematic for mobile, truck-mounted charging stations, as they'd need to carry a tremendous amount of energy in the form of fuel or batteries. Another problems may appear such as clouds, fog or dust which can scatter the laser beam.

Another idea for maintenance of UAVs' long endurance

flights is in collecting solar energy. An ambitious project has been launched to develop an ultra high-altitude solar powered UAV which can hover at an altitude of 20 km for several months [3]. But such an idea is applicable rather for unmanned airplanes with big wingspan, than for multicopters. For example, the mentioned UAV will have a wingspan of 40m, to which solar cells will be attached.

Variants for maintenance of UAVs' long endurance flights without landing described above are very expensive.

Alternative direction is continuous duty of drones which swap each other periodically. Arrangement of continuous duty would be possible under presence of a terrestrial charging station and a group of UAVs. When one is on duty at the object, other UAVs are on the charging station. Before the flying UAV's battery would be fully discharged, the changing of UAVs must be done: the duty multicopter have to land onto the charging station and another one (fully charged) goes to the object.

Control of charging for each UAV and dispatching such a group is not a simple task. All the more so, all control must be realized in automatic mode.

2. SYSTEM STRUCTURE

The proposed monitoring system includes the group of UAVs based on the charging station and the control station (Fig.2).

The control station ejects commands to UAVs and charging station and gathers tracking and telemetric information.

The most important part of the system is the charging station which includes a few charging terminals laying on the horizontal flat site and powered from the common source.

A few variants of realization (contact and noncontact) for charging terminals are proposed.

using UAV coordinates from the embedded GPS receiver. Then the accurate docking subsystem comes into operation. This subsystem includes a transmitter inside the charging terminal and an on-board UAV receiver. Such a short-range channel may be realized on the basis of radio, ultrasound or infrared devices. But the landing subsystem may be non-active (without transmitter).

A few systems are known which were developed for indoor applications and include small landing platforms for recharging batteries of multicopters [4, 5]. High accuracy of control and landing in such systems are achieved due to video cameras allocated along the perimeter of a hall and a special on-board camera placed underneath the multicopter for searching and capturing the docking terminal. The camera is programmed to recognize a particular pattern, shown on the surface of the landing platform, and to compute the relative position of the UAV with respect to the landing station [6].

However the described systems are not applicable in conditions of open air. It is significant for the outdoor conditions that the wind impedes normal landing, so even under subsystem of positioning and landing the UAV's accidental drift from the center of landing terminal is unavoidable. The problem of reliable work of UAVs in outdoor conditions is especially pressing in regions of cold winter with negative temperatures and snowfalls.

The process of charging is the most difficult stage under conditions of negative temperatures. It is more problematic than the flight itself, because of the self-heating of accumulators takes place during flight and battery works normally. But recharging of cold accumulators, when values of temperature are below -10 ºC, is difficult or impossible. So it is reasonable to arrange charging stations as temperature stabilized hangar (garage), in which the recharging could be implemented in normal conditions (Fig.3).

The idea to use a thermostabilized garage for a single UAV under winter conditions is shown in [7].
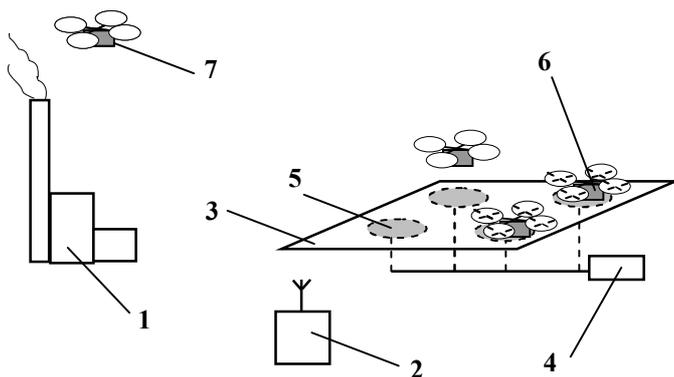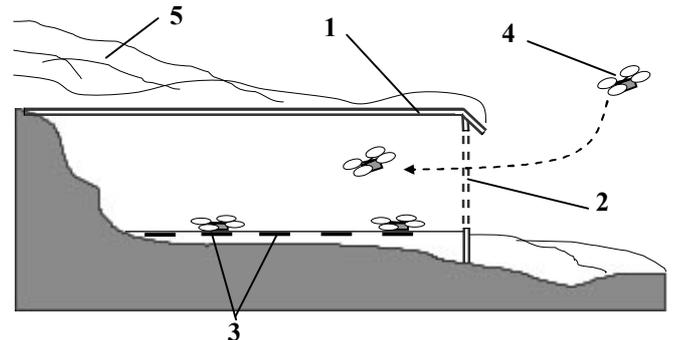

Fig.2. Structure of the continuous monitoring system:
1- object under investigation; 2 – control station; 3 – charging station; 4 – power source; 5 – charging terminal;
6 – UAV being charged; 7 – duty UAV

Fig.3. Garage for UAVs:
1- garage cover; 2 – automatic gate; 3 – charging terminals;
4 – UAV; 5 – snowdrift

The most difficult and critical operation in the system functioning is the landing approach of the UAV and its accurate positioning on the charging terminal. Rough approaching to the terminal is executed by the flight program

Besides temperature stabilizing subsystem such a garage must contain control subsystem for automatic opening/ closing a gate in time of a next UAV takeoff/approaching. Of course, in-flight maneuvers through the garage are more

complicated than simple landing onto a flat platform, but it is not a problem for multicopters which could be programmed for such tasks.

In addition, application of a garage as a landing station makes possible and gives good conditions for allocating inside the garage subsystem for positioning and docking on the basis of video cameras.

3. CHARGING TERMINALS

A few variants of realization for charging terminals are proposed. All of them may be classified into 3 groups:
1) 2-contact terminals;
2) 1-contact terminals;
3) non-contact terminals.

3.1. 2-contact (2-pole) terminals

2-contact terminal is a device with two traditional connectors (+, -) which provides a common DC charging chain including a power source and an on-board accumulator. The obvious advantages of such a variant are simplicity of charging circuit and minimum of energy losses. Disadvantages are high demands of galvanic coupling quality and necessity of very exact UAV landing onto the terminal pad.

The following solutions were proposed for neutralization of landing inaccuracy.

1) Funnel-shaped connector.

It is important to connect corresponding on-board and ground-based contacts precisely during landing. Connection system, shown in Fig. 4, could neutralize UAV's accidental deviation from the desired vertical landing trajectory by means of a vertically installed docking tubular shaft with 2 contacts above and on-board connector with a funnel-shaped mouth directed downward.
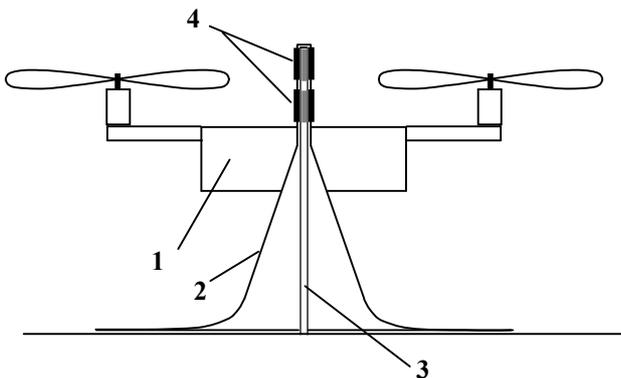
Fig.4. Scetch of a multicopter with a funnel-shaped connector:
1- multicopter; 2 – funnel; 3 – docking shaft; 4 - contacts

2) "Crawling" UAV.

Various mobile robots, being able to move on the surface, often have a subsystem for searching a stationary docking station, approximation and automatic connection to its wall-mounted or floor-standing recharging terminals [8].

So, it would be easy to combine a multicopter with a self-docking mobile robot [9]. Such a hybrid could be realized, for example, on the basis of four-wheel carriage with a

horizontal docking shaft (Fig. 5). After landing the hybrid UAV must begin to search a docking station implementing rotations and "crawls" for approximation to it.
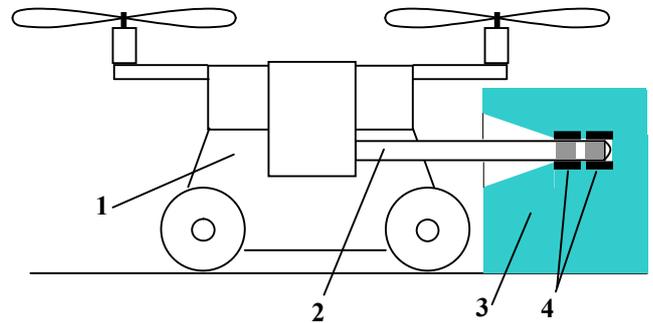
Fig.5. Scetch of a multicopter moving on the ground to the nearest docking terminal:
1- multicopter with additional driving actuator for wheels;
2 – docking shaft; 3 – docking terminal; 4 - contacts

3) Smart contact array.

The idea is that an UAV provided with 2 undercarriage electrodes (ski-like long and flat metal strips connected with poles of on-board battery) lands onto the field of many small contact pads ("smart contacts"). Size of each pad and clearances between them are chosen by such a way that one on-board undercarriage electrode could cover and close a few contact pads, but in any event two heteropolar undercarriage electrodes couldn't close each other (Fig. 6).
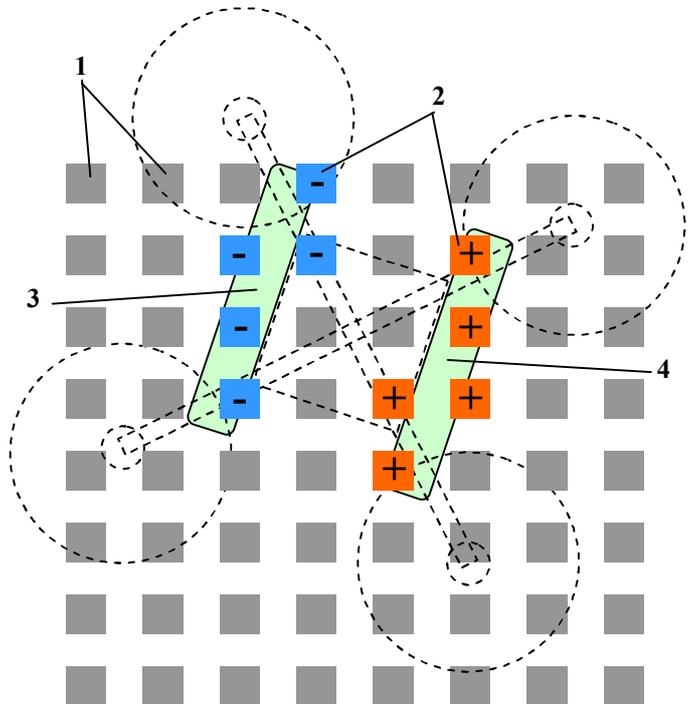
Fig.6. Distribution of activated pads in the smart contact array after UAV's landing:
1- nonactivated pads; 2 – activated pads; 3 – negative undercarriage electrode; 4 – positive undercarriage electrode

Each smart contact is able to analyze the voltage (which may be weakened) applied to the pad due to the UAV's landing and touching the pad by undercarriage electrodes. After analyzing the connection to the charging source takes place so that the positive pole of the source is connected to the positive pad and the negative pole is connected if the pad is negative.

Thus, we have automatic connection of the ground charging source to the on-board battery electrodes by the right way even under conditions of inaccurate landing.

The scheme of a single smart contact is shown in Fig.7. Noninverting amplifier DA1 amplifies the voltage applied to the contact pad X1 up to the level of saturation. This amplifier is able to yield rather large values of current (battery charging current) due to the pairs of powerful transistors VT1, VT2. Relay K2 (of solid state or electromechanical type) triggers under output voltage of either polarities and connects the amplifier output to the contact pad X1.
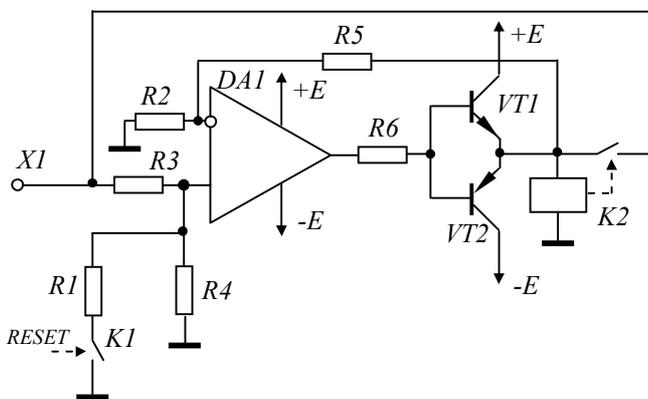

Fig.7. Electric circuit of "smart contact"

Thus, if the nonzero voltage is applied to X1 then the voltage of the charging source (E) in the same polarity will be applied to the same point X1. It will be sustained due to positive feedback until the end of the charging process. The special on-board charging controller implements the charging algorithm corresponding to the used type of accumulators (LiPo, LiFe). After the UAV flies away, the short reset pulse comes from the control unit to the key K1 which nulls the input voltage of DA1, then the relay K2 trips, the voltage on X1 drops to zero, and the contact pad comes back to the standby mode.

3.2. 1-contact terminals

1-contact terminal bases on high frequency energy transmission through only one wire. Possibility of such a way is known and discussed from the times of Tesla [10]. In this case there is no need to position UAV precisely, because of the landing place corresponds a solid metal pad of a rather big size. Efficiency factor of such a terminal is lower than the same for traditional 2-contact terminal.

3.3. Non-contact terminals

A wireless charging terminal bases on high frequency (10 kHz..100 MHz) energy transfer from the terrestrial source to the on-board accumulator charger by means of

magnetically coupled resonant circuits [11].

Flat circuit coils (one of which is aboard, another one is under landing pad) have to be close to each other as much as it is possible for high efficiency of energy transfer. Exact UAV of in the centre of the landing pad is not required, - it is sufficient if the UAV is inside the terrestrial circuit coil, which must have a size of a few times greater than the on-board coil.

Moreover, it is possible to distribute circuit coils on the charging station in such a way that makes all area of the charging station be available for landing and charging (Fig.8). This solution requires additional mechanism of detection and switching only the closest to the landed UAV terrestrial coil.
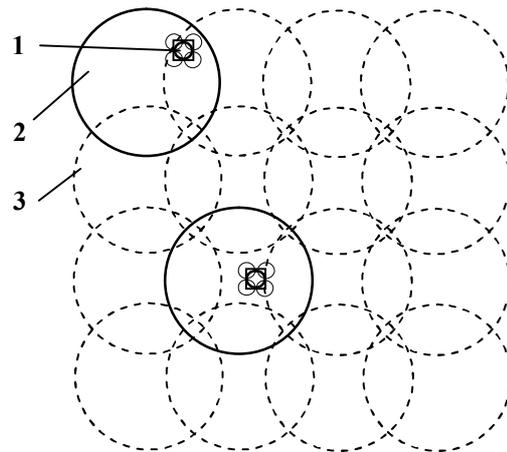

Fig.8. Possible distribution of terrestrial charging circuits on the charging station:
1- landed multicopter; 2 – activated charging circuit;
3 – nonactivated charging circuit

Many issues concerning interoperability of charging and being charged devices in wireless charging systems are developed in the so-called Qi standard [12] which specifies particularly interchange protocols. This standard might be a basis to design wireless charging stations for UAVs. But the current version of the standard makes no provision for transfer of power greater than 5W. It is expected to end such restrictions in the nearest version.

4. FLIGHTS SCHEDULING AND CHARGING

During the duty over the object information about a degree of discharge of the flying UAV battery is transmitted continuously to the control station. Besides, the control station receives information about degrees of charge for batteries of UAVs staying on the charging station. The control station generates commands for the flying UAV and for the staying UAVs in accordance with the received charge/discharge information and additional parameters and results of measurements such as temperature, strength and direction of the wind, UAV payload and others. Association of all these parameters helps to create and correct the schedule of flights and charging.

Fig.9. Virtual instrument panel of the dispatching system

Draft variants of the dispatching system were designed in LabView. The view of the developed virtual instrument panel is shown in Fig.9.

5. CONCLUSIONS

The proposed system extends capabilities of electric multicopters and shows the possibility of continuous monitoring arrangement by means of such UAVs.

Analysis of feasible realizations for docking/charging stations allows to conclude that today there is no indisputable direction of development. Alternative types of such stations have both advantages and disadvantages, and only practical experience of their application in the nearest future will show the best.

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