Recommendations for the use of unmanned aeronautical systems equipped with photo recording equipment for assessing the condition of the runway coatings in the polar regions

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Abstract: *A method has been developed and tested for determining the albedo of the underlying runway surfaces located in the polar regions with the help of unmanned aircraft systems and the combined use of a photo-recording device and actinometrical equipment. The relevance of the non-contact method for assessing melting and thawing of ice in the Arctic and Antarctic regions is substantiated. The proposed original method is based on the use of an available measuring technique, which makes it possible to correctly estimate the albedo, reducing by several times the time spent on collecting data on large areas in hard-to-reach areas. The theoretical probability of using the proposed technical solution, and the results of its test tests in the polar regions with the help of high-tech equipment and unmanned aircraft systems of the simplest technical means are considered. Based on obtained results, an analysis was made of the operation of unmanned aircraft systems for assessing the state of runways and the application of the concept to the potential improving of the ways to collect field data in polar regions. The developed method of the hardware-software complex provides the possibility of fast and high-quality data collection on large areas, on the runways of the Arctic and Antarctic airports by the contactless method.*

Key Words: *Arctic, aircraft, runway, snow cover, solar radiation method, albedo, testing*

1. INTRODUCTION

The geographical location of the Russian Federation highlights the pronounced regional isolation of the Arctic zone of the Russian Federation (AZRF). In Russia, more than 40% of the territories are inaccessible and remote polar regions – the Arctic, which requires the use of aviation technology (airplanes and helicopters) to ensure uninterrupted aviation and transport accessibility of the Russian Arctic. In these regions, as nowhere else, the issues of increasing the volume of passenger and freight traffic [1], [2], [3], [4], [5], [6], [7], [8], increasing the efficiency and reliability of operation under severe infrastructure and climatic constraints (ICC) are significant.

The use of an air fleet requires continuous monitoring of the runways. The increase in temperature in the Arctic region has led to the melting of 40% of the ice cover over the past forty years [8], [9], [10], [11]. This fact makes the monitoring of work surfaces covered with snow-ice cover relevant. The growth of the activity in the polar regions of the Russian Federation depends on the availability of dedicated aircraft for polar exploitation in the fleet of domestic aviation [1], [4], [5], [6], [7], [12].

The solution to the problem of uninterrupted aviation and the transport accessibility of the Far North and Far East regions is a compromise of the aircraft technical and working characteristics. In Fig. 1 shows the tendency to growth of the open sea zone in the Russian Arctic, but this means, where there is no open water yet, the ice has a thaw. The thickness of the ice decreases. And this affects the possibility of the organization on the ice runway.

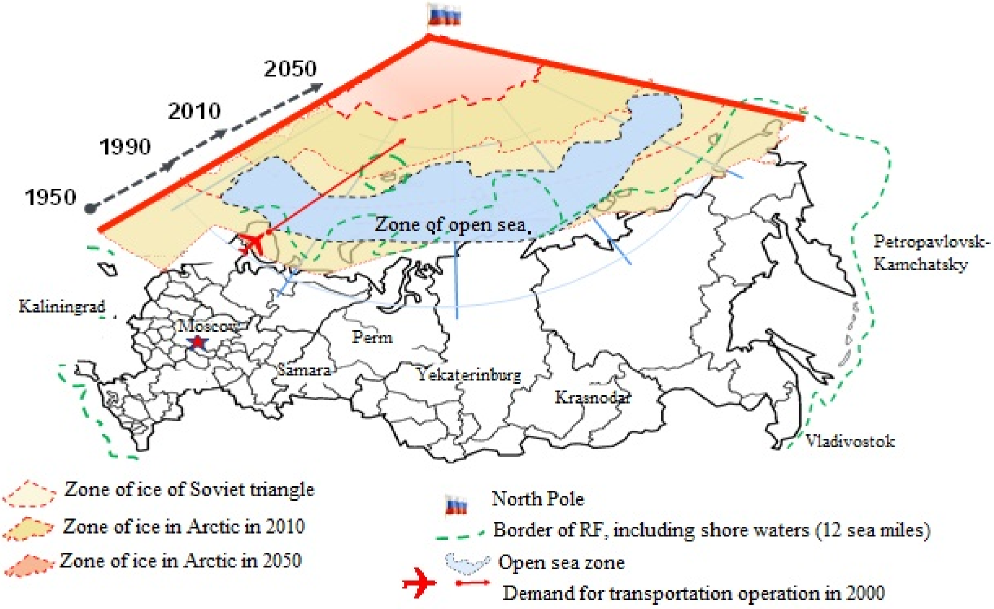


Fig. 1 – The tendency to increase the open sea in the Russian Arctic

To ensure the operation of aircraft and helicopters in the Arctic, constant monitoring of the runway surface is essential. One of the methods is contactless albedo method [13], [14], [15], [16]. Measuring the value of the diffuse reflectivity of a surface, which is expressed as the ratio of the intensity of radiation reflected from the surface to the intensity of radiation falling on it [16]. Today, in spite of the high significance of the albedo characteristic when calculating the energy balance of the surface and modeling the hydro meteorological parameters, measurements of the integral albedo "in situ" are performed by archaic methods and are deprived of the possibility of operational point measurements on large areas. This imposes strict restrictions on the volumes of data obtained, the accuracy of models that take into account this parameter, and as a result – the results of the simulation itself. Albedo calculations by means of satellite observations, in turn, provide information on the average size of the albedo area, and strongly depend on the combination of favorable weather conditions and the residence time of an artificial earth satellite over a specific portion of the surface under study.

The accumulation, handling, systematization and analysis of new data can significantly affect the refinement and improvement of existing thermodynamic models describing the climate of individual regions and the climate system as a whole. The main objective of the research is to estimate the albedo of natural and artificial snow-ice surfaces using remote and ground-based measurement methods. To achieve the set objectives, it is necessary to perform the following tasks:

- to test various types of unmanned aircraft systems (UAS) (quadcopter, tethered balloon) to evaluate the radiation characteristics of various types of snow-ice surfaces (glaciers, fast ice, drifting ice);
- to conduct ground-based measurements of incoming and reflected radiation in different spectral ranges on typical underlying surfaces (glaciers, fast ice, runway);
- to obtain new albedo data for surfaces (areas), a visit to which is technically unmanageable (marginal zones of glaciers, drifting ice of various cohesion, ice cover of lakes, etc.).

2. METHODOLOGY

Studies of the albedo of snow-ice surfaces of various types: the marginal zone of the glacier, fast ice, drifting ice, snow cover of the runway were done at Progress station in Antarctica during the 63 Russian Antarctic expedition. To test the methodology, a UAS “DJI MAVIC” and a tethered balloon, designed by the Moscow Aviation Institute (MAI), were used. A photometer LQ-190SA (LICER LTD, USA) and portable external specialized photographic equipment mounted on the UAS DJI MAVIC were used for the studies. The work was done according to the following plan:

1. Reconnaissance (search for the location of the survey according to the specified parameters) and the determination by poles of the route's edge points.
2. The division of the proposed location of making images of polygons (5x5, 10x10, 20x20 meters, depending on the expected height of the flight).
3. Trial launch of UAS without equipment for determining the time of flight of the route at a given height.
4. Installation of a warm balance (TB) mast with actinometrical sensors recording incoming and reflected radiation in two spectral ranges (400-700, 300-3000 nm).
5. Work with the use of UAS, with equipment fixed on its frame, at heights of 1.6, 3, 5, 10, 20 meters from the starting point.
6. Completion of work. Reading data from the TB mast, photometer and UAS cameras.
7. Processing the results of filming.

The time of work, as well as weather conditions (atmospheric phenomena) during the filming period were recorded in a special journal. Further will be used the developed by D. M. Zhuravsky algorithm [15], which allows to estimate the surface albedo using photo-recording equipment. The method is based on the analysis (processing) of photographic data obtained. When analyzing the collected data, the exposure data, affecting the exposure, the parameters of the lens and the photo-recording device, the data of the shooting parameters are taken into account to calculate the brightness of the underlying surface. Brightness is normalized to eliminate the effect of exposure error. Albedo is presented as a function of measured total solar radiation (weather station or remote station) and normalized brightness.

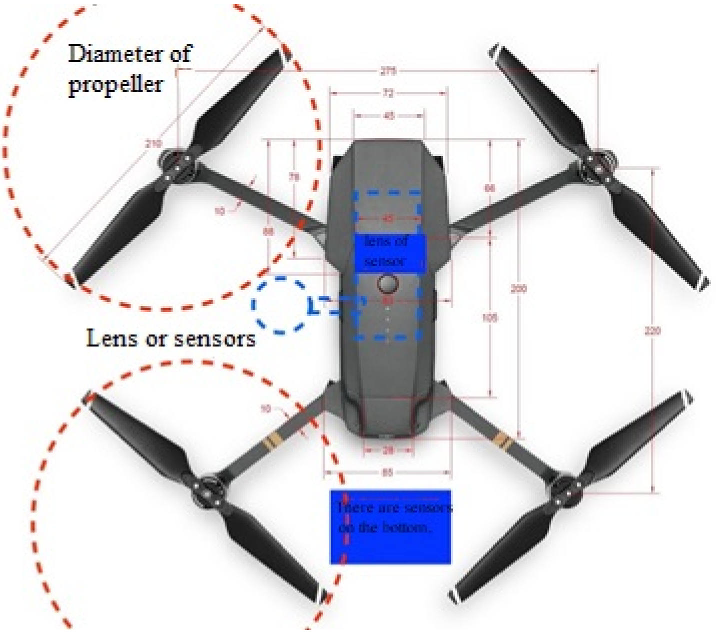
This algorithm is a modern adaptation and logical continuation of the methods proposed in 1955-66 by AARI employee A. P. Koptev [1], [2], [3], [13], [14], [15]. These studies present methods for calculating the albedo of clouds, water, and snow-ice surface according to aircraft actinometrical observations. Taking into account that more than 50 years have passed since the indicated publications, the current updating of the method is necessary in connection with the active development of UAS.

3. RESULTS AND DISCUSSIONS

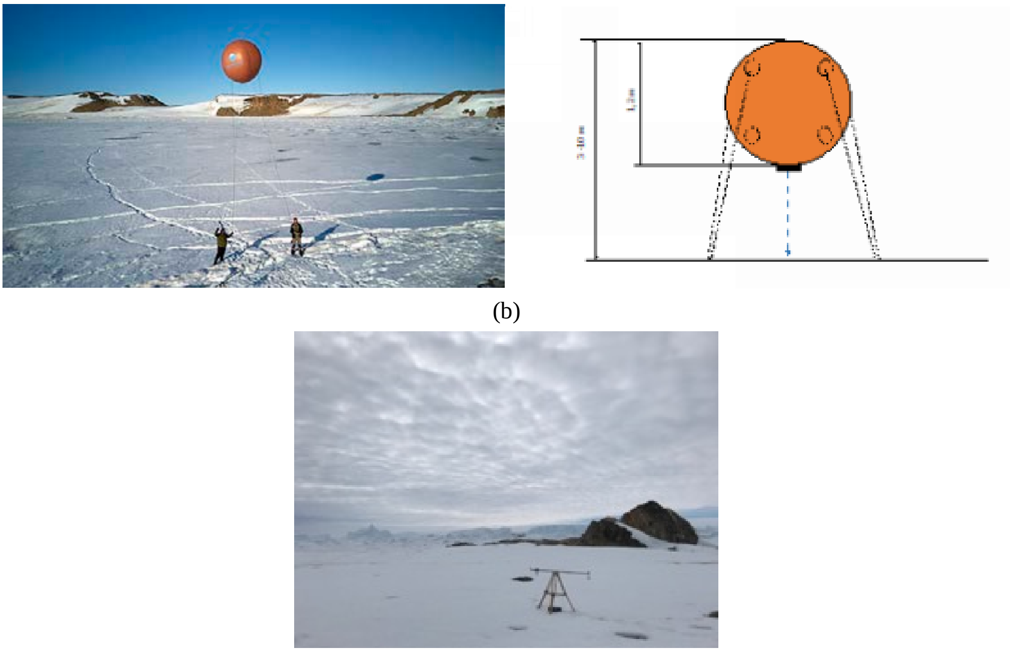
All types of standard and special actinometrical observations were done in accordance with generally accepted standard techniques (Manuals and RD) and special techniques developed in the department of interaction between the ocean and the atmosphere of the AARI.

Measuring instruments (MI), presented by various types of actinometrical sensors, were located on the TB (height 1.6 m above the surface level). Pyrometers M-80 (measurement range 300-3000 nm) and photometers LI-192SA (400-700 nm) for measuring incoming and reflected solar radiation were installed in cardan suspensions. The means of registration (MR) included the ADC "Data-Logger LI-1400", intended for registration and accumulation of signals from actinometrical sensors of various types (pyrometers, photometers). All MI and MR were grounded and connected by multi-conductor shielded cable lines.

The measurement discreteness was 1 minute and consisted in a sequential survey of all actinometrical sensors. Each sequential recording included a time stamp (UTC), a measuring channel number and an output signal (mV, μA).Later this information was processed using the appropriate conversion factors contained in the calibration certificates of the respective sensors. Reading the accumulated information from the ADC was done after each shooting session using a personal computer (PC). Each time interval is linked to a separate file in the <xls> format, the information from which was used for further calculations of the characteristics of energy and mass transfer. The main types of UAS and ground heat balance installation are presented in Figures 2 *a*, *b*, *c*.



(a)



(b)

(c)

Fig. 2 – Quadcopter DJI MAVIC (a), tethered balloon (b), the stationary heat mast (c)

The main technical characteristics of UAS and actinometrical sensors are presented in Tables 1-3.

Table 1. – Technical characteristics of UAS

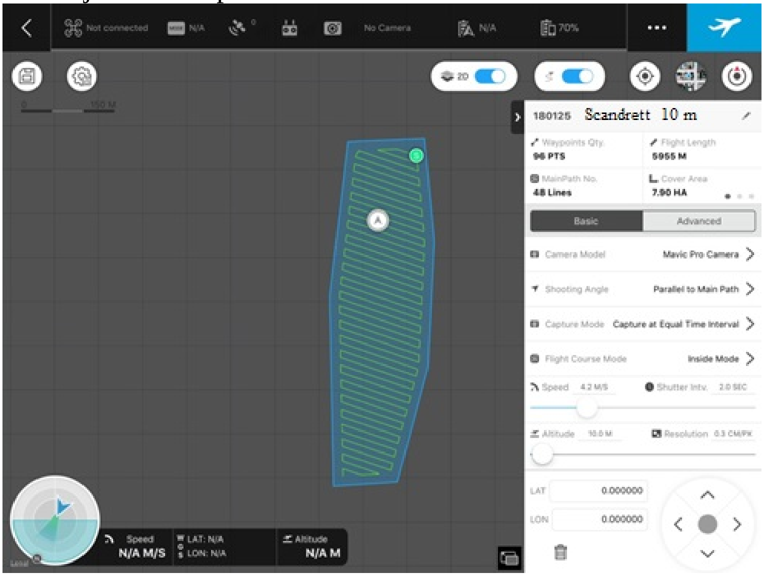
Parameter	**Characteristic**
DJI MAVIC PRO (PRC, 2017)	
Weight (including battery)	800 grams
Diagonal size (without propellers)	350 mm
Payload mass	300 grams
Maximum altitude above takeoff point	500 m
Flight time	about 25 minutes
Supported Satellite Navigation Systems	GPS and GLONASS
Camera 1 " CMOS; effective pixels:	20 MP
Operating frequency	2.400 – 2.483 GHz and 5.725 – 5.825 GHz
Working temperature	from 0° to 40°C
Accumulator battery	6000 mAh LiPo 2S
Operating current	1.2 A at 7.4 V
Battery type	LiPo 4S (Li-Polymer)
Payload	devices are installed on the external suspension of UAS
Balloon 2-2017 (RF, 2017)	
Weight (shell)	2000 grams
Ball volume	4 m^3
Filling:	class B helium

The size of the diagonal (in the inflated state)	200 cm
Payload mass	1000 grams
Cable length	10 m, attached to the ground for 2 loads of 10 kg
Maximum (limiting) flight altitude above take-off point	50 m
Flight altitude	from 2-5 m
Flight time	unlimited, once every 12 hours a swap of 30% is required
Supported Satellite Navigation Systems	not
Working temperature	from 0° to -20°C
Payload	devices are installed on the external suspension of UAS

Table 2. – Technical characteristics of the ADC installed on the UAS case

Weight (device and box)	**500 grams**
Dimensions	115x90x80 mm, typical box REA G221C
Device architecture	based on RASPBERRY
Supported Satellite Navigation Systems	GPS / GLONASS
Camera	1 " CMOS; effective pixels: 5 mp
Working temperature	from 0° to -10°C
Accumulator battery	1000 mAh LiPo 2S, operating time about 360 minutes
Operating current	1.2 A at 7.4 V
Battery type	LiPo 4S (Li-Polymer)

Figure 3 shows the working screen for calculating the trajectory (planned projection) of a quadcopter flight. The orientation of the segments, the frequency of measurements affects the result and are the subject of independent research.



180125 Scandrett 10 m

Waypoints Qty. 96 PTS

Flight Length 5955 M

MainPath No. 48 Lines

Cover Area 7.90 HA

Camera Model: Mavic Pro Camera

Shooting Angle: Parallel to Main Path

Capture Mode: Capture at Equal Time Interval

Flight Course Mode: Inside Mode

Speed 4.2 M/S

Shutter Intv. 2.0 SEC

Altitude 10.0 M

Resolution 0.3 CM/PX

LAT 0.000000

LON 0.000000

Speed N/A M/S

LAT: N/A

LON: N/A

Altitude N/A M

Fig. 3 – Calculation of the trajectory (planned projection) of the quadcopter flight

The deficiency of a nationally formed scientific and methodological support and practical recommendations for conducting research using UAS in the polar regions requires a modern answer in the form of recommendations that groups and specialists should use when conducting research (performing scientific programs) or performing other activities in the polar regions, including information to ensure the safety of infrastructure. It should be noted that scientists performing their research using UAS in the interests of scientific organizations and operators of the countries of the Antarctic Treaty countries, in 2015, the COMNAP working group specially prepared recommendations on the certification and management of UAS when conducting research in the Antarctic [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31].

4. CONCLUSIONS

Numerical simulations have been performed to investigate the performance of the proposed adaptive controller. For the sake of rigor, canonical coordinates transformation on system (10) was done and the zero dynamics were proved to be asymptotically stable, but with correction. The simulation studies validate the theoretical results. Furthermore, a close correspondence between these new findings and recent results has been found. But, in the final, we note a neglected feature in the literature of the field: the fitted key parameters of back stepping, $k_1 > 0$, $k_2 > 0$, $k_3 > 0$, $\rho_\alpha > 0$, do not ensure a large parameter robustness of the performance, see Table 1. The “admissible values” in the Table refer to that parameters limits which do not compromise the actual servo time constant and, in fact, the stable response of the system to the specified step input; see Fig. 3 for the case of maximal admissible value of τ. The sensitivity to some system parameters – c, S, p_a – is to be underlined. Thus, future works need to pay attention to these robustness aspects of the back stepping controllers.

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