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Experience of using unmanned aerial photography systems for mapping the territory of the Russian Federation

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Abstract

The analysis of the methods of remote sensing of the Earth (remote sensing) used in mapping the territory of the Russian Federation (satellite imagery, aerial photography from manned and unmanned aerial vehicles - UAVs) is given. The economic, technical and organizational factors influencing the choice of remote sensing method for the purposes of mapping the territory of the country indicated. The advantages of the UAV method are shown. These advantages include lower financial costs of carrying out cartographic works in limited areas, the speed of surveying and obtaining images, the ability to survey from low altitudes, including under low clouds, and obtain high-resolution images. The disadvantages of surveying using UAV include lower productivity on large survey area, restrictions on access to certain territories (depending on terrain, remoteness, and other obstacles), limitations in the ability to install additional equipment to improve the quality and capabilities of aerial survey materials, and increased insurance risk of use. At the same time, taking into account all the positive and negative factors, there is a tendency for the gradual outstripping development of aerial photography from the UAV. Along with the progress in the development of UAVs, this is facilitated by the current situation in the country with a decreasing number of manned aircraft used for aerial photography. Important conditions and the main factors stimulating the UAV demand for their successful implementation and use are improving the quality, reliability, safety and warranty period of UAV operation, development and production of aerial photography equipment for UAV. An important role is also given to changes in legislation that favor the use of UAV, the partial replacement of the aging fleet of manned aircraft used for aerial photography with unmanned systems. The main characteristics of unmanned aerial vehicles of light and medium type necessary for solving production tasks in the field of cartography and cadastre are specified. The main characteristics of on-board equipment for light and medium-type of unmanned aircraft system (UAS) necessary to meet production tasks are given, as well as the main technical requirements for light and medium-type UAS software. The features of photogrammetric processing of remote sensing data obtained with the help of UAS, the need to perform research tests of complexes of technical and software tools for digital aerial photography and photogrammetric processing based on the use of UAS are noted. The conclusion contains findings and recommendations.

Introduction

Currently, unmanned aerial vehicles (UAVs) are used in many fields of activity, including in the tasks of remote sensing of the Earth in general and aerial photography in particular. This application is most often and closely related to solving the problems of aerial topographic surveying of an area, for example, obtaining spatial data, creating orthophotoplans, but, as a rule, it is limited to relatively small objects in terms of area or length. For such objects, the benefits of aerial photography using UAVs are obvious and are due to its advantages listed below in section 3. At the same time, the planning of aerial photography with UAVs for solving mapping tasks should be based primarily on an analysis of economic factors (time and financial costs), taking into account the specific conditions of the object of photography and the hardware and software used.

1. Remote sensing methods of the Earth used in mapping the territory of the Russian Federation

Technologies for mapping the territory of the Russian Federation are based on the use of images of the Earth's surface obtained by:

– remote sensing of the Earth from space;
– aerial survey from manned aircraft;
– aerial survey from UAV;

Trends in obtaining raw images for topographic mapping are:

– increasing the resolution of satellite images (up to several dm), which significantly expands the scope of their use along with or instead of aerial photographs;
– strengthening the position of unmanned aerial photography systems, which dictates the need to take into account a certain "niche" of their effective use in topographic mapping and other tasks.

Along with these trends, classical aerial photography (from manned aircraft) of vast territories in order to create and update spatial information remains in high demand, as evidenced by the periodic coverage of the territory of individual countries with aerial photographs with an area resolution of up to 15-20 cm (Yegorov, Yadrikhinskaya, 2021).

In recent years, aerial survey methods based on the use of unmanned aircraft systems (UAS) have been intensively developing. This is largely due to the trend towards large-scale mapping, as well as the adoption of the National Project "Unmanned Aircraft Systems". The project covers a wide range of areas of development, implementation and operation of UAS. According to the analysis of the use of various remote sensing methods in mapping territories conducted by Roskadastr in the period 2022–2024 the share of aerial photography works performed using UAS has increased from 6% of the total volume of Earth remote sensing data to 34%.

Progress in the development and use of UAS is significantly improving the state of affairs in this area. This is facilitated by the variety of UAVs entering the market:

– by type of UAV (airplane, helicopter, multicopter, VTOL, Figures 1-4);
– by type of take-off and landing;
– by engine type and flight duration;
– according to the take-off weight and dimensions of the UAV, the weight and dimensions of the on-board aerial photography equipment installed on it;
– according to the maximum values of speed and altitude of flight;
– according to the operating conditions.

Figure 1. Geoscan 201 Geodesy

Figure 2. Helicopter BT 30E

Figure 3. Multicopter Geoscan 401 Geodesy

Figure 4. VTOL Legionnaire G29S

2. Factors influencing the choice of method of the Earth remote sensing

To date, the average annual volume of topographic surveys at scale the 1:2000 is tens of thousands square kilometers. The objects of surveying are rural settlements with an average area of 1 square kilometer, often located at significant distances from each other (Figure 5).

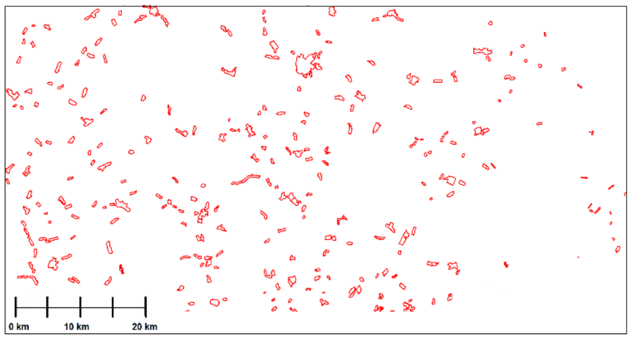

Figure 5. Aerial photography objects for mapping at scale the 1:2000

It is necessary to take into account a number of factors when choosing a method of remote sensing of the Earth for mapping purposes: economic, technical, organizational (Anikeeva et al., 2018), (Nekhin, Babashkin, 2022), (Nekhin, Rubenok, Kovrov, 2024).

In terms of economic factors, this includes accounting the cost of equipment, the costs of servicing technical equipment and performing work, as well as the productivity of the selected work technology.

As for technical factors, this is the satisfaction of the technological characteristics of the hardware and software used in the survey system, the requirements imposed on the characteristics and parameters of the created products in terms of accuracy, detail, efficiency, productivity, etc.

Organisational factors include accounting the available hardware and software, weather and seasonal conditions for aerial survey, the required deadlines and specific conditions for their implementation.

Economic factors are largely accelerating the trend of moving from manned to unmanned systems, despite the lower productivity and relative accuracy of unmanned systems. One of these important factors is the total cost of purchasing, maintaining and operating UAS, as well as the reduction of financial and time costs for training operators (remote pilots) and their work. The on-board aerial photography equipment and software also require significantly lower costs for their purchase and maintenance.

A comparative analysis of the costs of performing work processes (aerial survey, aerial triangulation, DTM generation, creating orthophoto mosaic) at scale the 1:2000 based on aerial photography materials obtained from manned and unmanned systems is shown in Figure 6.

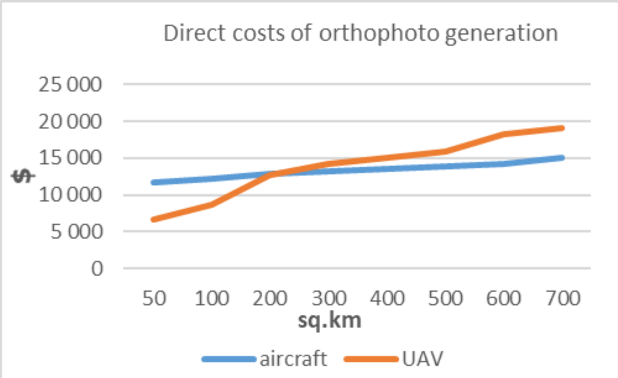

Figure 6. Comparison of costs of creating orthophotoplans at the scale 1:2000 using manned and unmanned aircraft

3. Advantages and disadvantages of the Earth remote sensing using unmanned aircraft

The main advantages of the technology for obtaining spatial data from the Earth remote sensing using UAS are:

– the operation and maintenance of UAVs requires significantly lower costs compared to manned aircraft, which is especially evident for relatively small areas requiring frequent operational aerial photography;
– aerial photography does not require an runway or a specially prepared site;
– the cost of a set of equipment for aerial photography, including the cost of the aircraft itself, is significantly lower;
– the speed of survey and taking pictures;
– the ability to survey from low altitudes (including under low clouds) and obtain high-resolution images.

The disadvantages include:

– higher relative (related to the height of photographing) errors in determining the spatial coordinates of object points from small-format camera images;
– lower productivity on large areas of survey;
– restrictions on access to certain areas (depending on terrain, distance and other obstacles);
– limitations in the ability to install additional equipment to improve the quality and capabilities of aerial survey data;
– an increase in the number of images for photogrammetric processing due to the forced increase in their forward and side overlap;
– increased insurance risk of application.

However, taking into account all the positive and negative factors, the situation is gradually changing towards the accelerated development of aerial photography using UAS. This is facilitated by the situation in the country with a reduction in the number of manned aircraft used for aerial photography, as well as progress in the development of unmanned systems.

4. Tasks for expanding the use of UAS in the field of mapping and cadastral surveys

According to the Order of the Government of the Russian Federation "On approval of the Strategy for the development of unmanned aviation in the Russian Federation for the period up to 2030 and for the future up to 2035 and the plan of measures for its implementation", the unmanned aviation industry is considered not only in terms of the market for manufactured unmanned aircraft systems, but also the market for services provided using unmanned aircraft systems.

The National Project "Unmanned Aircraft Systems" covers a wide range of areas of development, implementation and operation of UAS and includes a number of federal projects:

"Stimulating demand for unmanned aircraft systems";
"Stimulating the development and serial production of unmanned aircraft systems and components";
"Development of infrastructure for the operation of unmanned aircraft systems and ensuring flight safety";
"Improving the efficiency of the certification and standardization system for unmanned aircraft systems";
"Personnel for unmanned aircraft systems".

In the Russian market, works in the field of mapping and cadastre is one of the most significant among other types of works carried out using unmanned aircraft systems (topographic mapping, cadastral, control (supervision) activities in the field of land use).
Their goal is to create a new industry of the Russian economy that is competitive in the domestic and global markets in the field of operating unmanned aircraft systems to provide consumers with spatial information and analytical services.

The planned need for UAS for mapping and cadastre purposes for the next three years is several hundred units. Important conditions and the main factors stimulating the demand for UAS for their successful implementation and use, should be:

– improving the quality, reliability, safety and warranty period of the UAV;
– development and release of domestic UAS aerial photography equipment;
– changes in legislation (the Air Code, Federal Aviation Regulations on the Use of Airspace, etc.) that favor the use of UAS;
– partial replacement of the aging fleet of manned aircraft used for aerial photography with unmanned systems.

At the same time, the successful implementation of UAS in practice largely depends on improving the reliability and safety of the UAS being developed, in particular, the activities of federal projects should provide for a significant increase in the warranty period of UAV (which currently in most cases is limited to 70-100 flights). This is necessary to harmonize with the terms of use of expensive on-board aerial photography equipment, the warranty period of which is about 7 years.

To ensure the operation reliability and safety of the developed UAS, measures should also be provided for their mandatory equipment with an automatic collision prevention system ("Everyone sees others, and others see everyone"), noise-resistant GNSS equipment.

5. Equipping the UAS with on-board aerial photography equipment

It is planned to organize mass production and supply a range of on-board equipment and software to ensure topographic aerial photography on the basis of the UAV:

- digital aerial cameras;
- aerial laser scanners;
- inertial systems and GNSS equipment;
- on-board equipment and software (transponder, collision avoidance system, etc.);
- flight management systems;
- software for processing airborne aerial survey data.

Based on domestic developments in the field of on-board aerial photography equipment and software products for automated photogrammetric processing on the basis of artificial intelligence (AI), well-defined requirements should be imposed on the UAV-based aerial photography system in terms of:

- carrier (UAV);
- aerial camera;
- on-board GNSS/IMU;
- aerial camera installations (gyro stabilization mounts);
- lidar.

Table 1 shows the main UAVs characteristics of light and medium types necessary to meet the operational tasks in the field of mapping and cadastre.

№	The name of the UAV's characteristics	The value of the characteristic for UAV	
		The light type	The medium type
1	UAV type	VTOL	VTOL
2	Engine type	hybrid, electric	hybrid, electric
3	Maximum payload, kg	5	30
4	Maximum take-off weight, kg	up to 30	85-100
5	Maximum flight altitude, m	at least 3000	at least 5000
6	Cruising speed, km/h	60 – 120	at least 120
7	Maximum flight time, h	6	at least 6
8	Range of the radio channel, km	at least 100	at least 200
9	Maximum crosswind, m/s	up to 12	up to 15

Table 1. UAV main characteristics of the light and medium type

Table 2 shows the main characteristics of an aerial camera for UAV of light and medium types, necessary to meet the operational tasks in the field of mapping and cadastre.

№	The name of the camera characteristics	The value of the camera characteristic for UAV	
		The light type	The medium type
1	Format of the camera	The small	The medium
2	Sensor type and size, Mp	CMOS, 40 – 100	CMOS, at least 100
3	Weight including lens, kg	no more than 1	no more than 4
4	Pixel size, microns	no more than 6	no more than 5
5	Image resolution, bit	12	12
6	Maximum frame rate, sec	at least 0,5	at least 1
7	FMC system	option	available
8	Shutter type	electronic or central mechanical	electronic
9	Type of onboard storage devices	SSD/ memory card SDXC	SSD

Table 2. Main characteristics of an aerial camera for UAV of light and medium types

Table 3 shows the main characteristics of an airborne laser scanner for UAV of light and medium types, which are necessary to meet the operational tasks in the field of mapping and cadastre.

№	Name of lidar characteristics	The value of lidar characteristics for UAV	
		The light type	The medium type
1	Pulse repetition frequency, MHz	at least 0,5	at least 2
2	Scan speed, Hz	20 – 100	50 – 150
3	Scanning angle, deg	75 – 100	60
4	Angular resolution, deg	no more than 0,001	no more than 0,001
5	Max. Operating Flight Altitude AGL, m	at least 500	at least 3000
6	Weight, kg	no more than 2,5	no more than 20
7	Power consumption, W	no more than 45	no more than 60
8	Dimensions (L x W x H), mm	220 x 110 x 130	400 x 300 x 300
9	Type of on-board storage devices	SSD	SSD

Table 3. Main characteristics of lidar for UAV of light and medium types

Table 4 shows the main characteristics of GNSS/IMU for UAV of light and medium types, necessary to meet the operational tasks in the field of mapping and cadastre.

№	Name of the characteristic	The value of the GNSS/IMU characteristic for UAV

	GNSS/IMU	The light type	The medium type
1	IMU type	fiber-optic	fiber-optic
2	GNSS multisystem	GLONASS, GPS, BEIDOU, GALILEO	GLONASS, GPS, BEIDOU, GALILEO
3	Weight, kg	no more than 3	no more than 3
4	Positioning accuracy, m	0,05 @ 350	0,005 @ 150
5	Roll and pitch accuracy, deg	0,008	0,003
6	True heading, deg	0,02	0,006
7	Dimensions (L x W x H), mm	100 x 60 x 20	120 x 115 x 150
8	Memory capacity, GB	at least 64	at least 64
9	Type of onboard storage devices	SD Card	SD Card / SSD
10	Data recording in IMU, Hz	at least 256	at least 400

Table 4. Main characteristics of GNSS/IMU for UAV of light and medium types

Table 5 shows the technical requirements for the software for UAV of light and medium types necessary to meet the operational tasks in the field of mapping and cadastre.

№	The main functions of the software for UAV of light and medium types
1	Mission planning
2	Aerial survey performing
3	Copying survey data from on-board mass memory
4	Post-flight processing and survey quality control
4.1	GNSS/IMU data processing
4.2	Generation and output of laser points in the LAS format
4.3	Adjustment of laser point clouds
4.4	Creating and output of control report
4.5	Converting photos to TIF format;
4.6	Radiometric correction of aerial images
4.7	Calculation of the elements of the external orientation of aerial images

Table 5. The main technical requirements for the UAV software

6. Regulatory and legal support for the implementation of UAS

6.1. Legal regulation

Currently, legal regulation lags behind modern requirements for the operation of UAS in terms of removing or limiting organizational barriers.

In the opinion of many UAS operators, urgent tasks requiring operational solutions should be:

– simplification or exclusion of the UAS operator certification procedure;
– simplification of measures related to the implementation of requirements for equipping UAS with appropriate equipment, including cryptographic protection of information obtained as a result of remote sensing of the Earth;
– simplification of measures for the implementation of aerial photography with UAS, concerning:

the procedure for obtaining permits to conduct aerial surveys and (or) other methods of remote sensing of the Earth from an unmanned aircraft, obtaining and using their results;

simplification of the procedure for approving the use of airspace in the production of aerial photography.

In order to increase the effectiveness of the use of UAS for topographic aerial photography, it is necessary:

– to ensure their permanent unrestricted access to the use of the airspace of the Russian Federation beyond the line of sight;
– improve legislation in the field of operation of unmanned aircraft systems by individuals and legal entities regarding the possibility of introducing a notification procedure for aerial photography flights 30 to 60 minutes before their start;
– to improve legislation in the field of the use of materials obtained as a result of aerial surveys and (or) other methods of remote sensing of the Earth in terms of promptness increasing the efficiency of obtaining their results.

6.2 Regulatory technical documents

The replacement of analog aerial photographs with digital ones, the highly accurate determination of the elements of the external orientation of images based on satellite and inertial on-board systems, and the rapid development of UAS dictate the improvement of national standardization in this area.

In recent years, national standards of the Russian Federation have been developed (National standard of the Russian Federation GOST R 59328-2021), (National standard of the Russian Federation GOST R 59562-2021), (National standard of the Russian Federation GOST R 70078–2022), National standard of the Russian Federation GOST R 71863-2024), National standard of the Russian Federation GOST R 70846.17-2024). These documents regulate in sufficient detail the requirements for performing aerial photography and airborne laser scanning with UAVs in terms of technical requirements:

– to the aerial survey system, its composition and technical characteristics;
– to the design of aerial photography and airborne laser scanning and its parameters;
– to the software and hardware complex for processing aerial photography and lidar data;
– the quality of aerial photography and lidar data;
– to the completeness and design of the data obtained as a result of remote sensing.

6.3 Use of measuring instruments

The GNSS system and the laser scanning system used in the UAS must be entered in the register of measuring instruments of Rosstandart and verified in accordance with current regulatory requirements. Their metrological support is carried out using state working standards, selected in strict accordance with the requirements of the State Verification Scheme for coordinate-

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time measuring instruments and the necessary margin of metrological accuracy.

7. Features of photogrammetric processing of the Earth remote sensing data obtained using UAVs

The specificity of aerial photography using UAVs is that the quality and accuracy of the resulting spatial data depends on the entire range of software and hardware, including photogrammetric processing (Babashkin, Kadnichanskiy. Nekhin, 2020).

The features of photogrammetric processing of the Earth remote sensing data obtained using UAVs are:

– significant volume of aerial images processed due to their smaller format in relation to a manned aircraft;
– increased values (up to 80-90%) of aerial images overlapping and their significant instability;
– increased requirements for the automation of selection and determination of coordinates of tie points on overlapping images;
– increased requirements to the computer of photogrammetric processing.

The accuracy of the final product obtained from UAV aerial photography depends on:

– the aerial camera specification;
– properties of the aircraft from which aerial photography is performed;
– availability and parameters of the gyro stabilization mount;
– quality (accuracy) of the on-board GNSS receiver;
– characteristics and capabilities of photogrammetric processing software.

The quality of an aerial camera is determined by the stability (constancy of values) of its interior orientation elements and is ensured by its design characteristics and image geometry, which should allow the reconstruction of a bunch of rays from the calibrated values of interior orientation elements with the required accuracy (within a pixel).

The properties of the UAV are characterized by aerodynamic qualities (acceleration and speed of random angular movements), which must be minimized by the permissible angular "shift" of the image and the design properties of the gyro stabilization mount, ensuring high photogrammetric quality of aerial images by sustaining the required overlap values and the permissible lateral drift along the course.

The accuracy of the on-board GNSS receiver determines the requirements for the need to use control points and their density, which ensures the specified accuracy of the final product, or makes it possible to dispense with the use of ground control points.

The capabilities of a photogrammetric processing software tool are characterized by the quality of the methods and algorithms implemented in it, as well as the compliance of the mathematical model implemented in the software product. The software must take into account the mathematical model of surveying by the type of camera used, described by a specific set of interior orientation parameters, the values of which are obtained as a result of photogrammetric calibration.

When using technical and software tools for aerial photography and photogrammetric processing in various operating conditions, it becomes necessary to assess the accuracy of the final product: orthophoto, digital elevation model, digital terrain model, and other products. For this purpose, research tests are carried out on complexes of hardware and software for digital aerial photography and photogrammetric processing based on the use of UAVs.

The purpose of such research tests is to establish the metrological qualities of a complex of technical and software tools for digital aerial photography and photogrammetric processing under certain conditions and performance characteristics:

– survey altitudes at which tests are carried out;
– required density of plan-height ground reference points;
– nominal forward and side overlap of aerial photographs, wind speed (permissible and actual);
– number of GNSS base stations;
– maximum distance of the UAS from GNSS base stations.

The determined metrological qualities of the complex of technical and software tools for digital aerial photography and photogrammetric processing are:

– relative (related to the survey altitude) average error in determining the plan position dS/H and height dH/H, characterizing the accuracy of photogrammetric determinations of the coordinates of clear contours from overlapping images of the block;
– relative average error in the altitude of terrain model points, characterizing the accuracy of the terrain (surface) model created using the complex;
– the average relative error of the horizontal position of clear contours on the orthophoto, characterizing the accuracy of the orthophoto created using the complex;
– the smallest size of a terrain object that can be displayed on an image (in m and in pixels), characterizing the actual resolution of aerial images and the "blur" of a digital image.

The research test program contains:

– the specific composition of the complex of hardware and software and their main technical characteristics;
– values of survey altitudes for which research is carried out;
– position scheme of control and check points, requirements for determining their horizontal and vertical coordinates;
– used coordinate and elevation systems;
– position scheme of aerial flight lines for each survey altitude;
– dimensions and configuration of marks for marking points, conditions, procedure and methods of testing;
– composition of the determined metrological qualities and their indicators.

8. Training of qualified personnel for UAVs

The implementation of the training program for specialists in the field of UAS is based on a systemic integrated approach of the federal project "Personnel for Unmanned Aircraft Systems". The participation of a large number of organizations engaged in educational activities presupposes the need for harmonization and coordination of joint activities, which can be implemented in terms of:

– development of modules on unmanned aircraft systems, ensuring their training in educational programs of higher

and secondary vocational education and additional professional programs, as well as basic vocational training programs;
– unified training of remote pilots for UAS in any educational organization that has the necessary material base according to the standard training programs for remote pilots for UAS with a weight of less than 30 kg approved by the Ministry of Transport of Russia;
– creating a regularly updated list of professions, skills, professional and educational standards, as well as mechanisms for assessing and recognizing qualifications in the field of operating unmanned aircraft systems.

According to expert estimates, the demand for personnel in the unmanned aviation industry may reach one million specialists in the development, production and operation of unmanned aircraft systems by 2030. Most of them are UAS operators, project team leaders, specialists in applied scientific, production and technical fields, UAS operation and maintenance specialists, as well as remote pilots.

To meet the personnel needs in the field of UAS application, a competency center has been created at the Public Law Company «Roskadastr», to implement a set of measures to improve the skills of existing industry workers, as well as retrain specialists who already have applied experience in the field of geodesy, cartography and cadastre.

Conclusions and suggestions

The applied mapping technology using UAVs must take into account the specific conditions of the work site, technical, economic and time indicators.
Planning of aerial photography with UAVs should be based, first of all, on an analysis of economic factors (time and financial costs), taking into account the specific conditions of the survey object and the characteristics of the hardware and software used, as well as regulatory documents governing the use of UAVs for mapping and cadastre purposes (in terms of regulation of aerial survey work, assessment of metrological characteristics of complexes, technology for obtaining various types of products, etc.).

An urgent problem is the development of an economical domestic aerial photography complex and on-board equipment for UAVs. Its improvement for the purposes of topographic mapping and cadastre should proceed through:
– increasing the flight duration of the UAV;
– increasing its carrying capacity;
– increasing the guaranteed service life;
– increasing autonomy and noise immunity.

An urgent task is to develop and equip UAVs with modern domestic on-board equipment, including medium format aerial cameras with a flight management system, a compact lidar with an inertial system and GNSS equipment, software for planning, managing and processing data from UAVs.

The photogrammetric method (including those based on aerial photography data obtained from UAVs) allows one to determine the spatial coordinates of objects with an error of several cm. At the same time, in a number of cases (dense vegetation, high-rise dense buildings), limiting its use for solving problems of mapping and cadastre, it requires the use of other methods (geodetic, satellite) in addition to it.

Improving aerial photography technology based on UAVs should follow the path of using professional methods and technical means (metric cameras, on-board equipment, stereoscopic image processing methods, etc.).

The effective use of UAS in order to obtain initial spatial information for topographic mapping and cadastre is associated with the urgent task of regulatory and technical support for technologies for their use, including standardization of time and financial costs for technological work processes.
Regulatory legal support for the implementation and operation of UAV should be developed at a rapid pace, adapted to modern conditions in terms of eliminating or limiting organizational barriers.

In the context of mass use of UAS, safety issues of their operation come to the fore, due to both objective factors (GNSS signal shutdown) and subjective factors related to the quality of training of remote pilots.

An important role in this regard is given to the training of qualified personnel in the field of UAS operation, including through advanced training, as well as retraining of specialists who already have applied experience in the field of aerial photography and photogrammetry.

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