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MONITORING OF REAL ESTATE OBJECTS BASED ON MATERIALS, OBTAINED FROM UNMANNED AERIAL VEHICLES

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Abstract. *Unmanned aerial vehicles (UAVs) are one of the types of platforms of surveying equipment in Earth remote sensing. The use of UAVs is effective in comparison with the use of manned aircraft when urgent updates of digital maps are needed, as well as monitoring of the occurring changes in small areas dispersed in space. In these cases, the use of manned aircraft will lead to unjustified costs, which is inexpedient from the economic point of view. In addition, the lack of favorable weather conditions often leads to a disruption in the performance of aerial photographs in the planned time, when the Aerial Survey is most effective and expedient. The use of only ground surveys also leads to an increase in the cost of work, and in some cases to the inability to conduct them (lack of access to protected territory, private property, etc.). In these conditions, the use of a remote-controlled aerial model, equipped with the necessary surveying and control equipment, which is easily delivered to the object of the survey, makes it possible to carry out aerial surveying quickly even in the absence of stable weather conditions necessary for the performance of traditional Aerial Survey. For the UAV application, a short-term "window" of good weather is sufficient. In addition, the possibility Aerial Survey of from low altitudes allows it to be carried out at low continuous clouds. The use of a UAV is effective when surveying linear objects, inventorying and cadastre of properties, as well as for obtaining operational information in emergency situations.*

Keywords: *Aerial photography, UAV, remote sensing, land monitoring, accuracy.*

Currently, there are several types of remotely controlled UAVs capable of carrying digital cameras. The resulting digital images are used for photogrammetric processing when creating and updating cartographic products, as well as for obtaining a variety of thematic information. At the Department of Aerial Photogeodesy of the State University of Land Use Planning, a technology for creating cartographic material using UAV has been developed and is constantly improving. The technology includes the following steps:

- the formation of a photographic complex with a description of the technical requirements of each module, the technical preparation of the complex;
- preparatory work for surveying, including calculations of aerial photography parameters to obtain the required accuracy of the cartographic material being created, development of a flight program and calculation of the photo centers coordinates, and then entering them into the on-board computer program;
- aerial survey;
- image referencing;
- orthorectification (output products - orthophotomaps);
- field interpretation of properties;
- vectorization of digital orthophotomaps according to field interpretation;
- obtaining vector plans;
- geometric accuracy of evaluation of the output products.

The technology of creating cartographic products from images obtained with UAV is similar to traditional.

However, there are a number of peculiarities due to the specificity of obtaining images. UAV is designed to perform aerial survey work on local areas of the terrain from heights of 200-1000 m in a radius of 10 km or more from a mobile control point. The flight control of the UAV is carried out in manual mode by the pilot-operator, located on the control point (the car with the equipment). The position of the UAV is assessed visually on the monitor screen, displaying the video image broadcast from the UAV by the traffic camera in real time. The monitor also shows telemetry data (altitude, speed and battery status), as well as UAV position on the digital map.

Of particular note are the problems of photogrammetric processing of images obtained by digital cameras from the UAV.

From the standpoint of the correctness of photogrammetric processing, special requirements arise for the surveying equipment and the aerial survey as well.

semi-professional or consumer digital cameras are used as a filming equipment. The cost of such digital cameras is much lower than the cost of used aerial cameras.

The choice of a digital camera used for surveying with a UAV must be determined by the following.

The image properties of the camera are characterized by two main parameters: geometric resolution and motion blur. Geometric resolution (pixel size) in professional digital cameras, as a rule, is 3-10 microns, which provides sufficient accuracy of measuring coordinates when photogrammetric processing of images.

Image motion blur caused by linear and angular movements of the UAV are eliminated by short exposure time. Therefore, the camera should have the maximum possible short exposures. When aerial surveying with UAVs of aircraft type, having a cruising speed of 80-120 km / h, the image blur will not exceed the permissible value of 0.02 mm. When using helicopter-type devices, as a carrier of cameras, which fly at low speed, the image blur is practically eliminated. The measurement properties of the digital image are characterized by the magnitude of the residual distortion. The effect of distortion is eliminated by a special program for converting a digital image according to the camera calibration.

The weak point of digital (not photogrammetric) cameras is the small size of the matrix - 1/3 ... .5 / 3 inches. The small size of the matrix leads to an increase in the number of images, which will further increase the volume of field and in-house work.

In addition, the small format of the matrix corresponds to a small aerial photo base (B), that leads to a not better surveying index K = B / H (H is the height of the survey). The surveying index determines the accuracy of the digital elevation model. The optimum value is K = 0.7-1.0. Therefore, the coefficient K must be adjusted by the height of the survey. In this case, the camera should be oriented so that the long side of the matrix is directed in the direction of the flight strip. In addition, for correct photogrammetric processing of images, the camera should be calibrated, i.e. the interior orientation parameters and the values of lens distortion must be determined with high accuracy.

The article presents the results of experimental studies on the effectiveness of UAV applications for creating orthophotomaps used for monitoring land in urban areas.

Aerial survey of the urban area was carried out with the UAV "Ptero". The 1 km^2 survey site is an open flat area, partially built up by multi-storey buildings.

The survey was done by a semi-professional calibrated digital camera Canon EOS5D. The camera is installed in the lower part of the fuselage of the UAV. Images were saved in a removable memory module (flash drive) and upon completion of the flight they were imported into the computer for analysis, viewing and preliminary processing.

The shutter response frequency (the exposure interval) was calculated taking into account the following parameters:

- the specified UAV speed;
- the required overlap of images;
- altitude above the ground;
- the opening angle.

The flight control of the UAV was performed remotely from a portable base station via a telemetry channel. The memory of the autopilot contains information about the direction of the flight strips and the photo centers coordinates.

Figure 1 shows the image obtained from a UAV on an urban area.

Figure 1. The image obtained from the UAV

Investigation of the geometric properties of images obtained with UAVs in this experiment

Initial data

The format of the frame is 36x24 mm (4368x 2912 pixels)

Survey Options:

- Focal length 30.87 mm (3746 pixels)
-
- Average flying height above ground 200 meters

Determining of the tilt angle of the image

The tilt angles of the image are unknown , as a rule, or known approximately. In our studies, as a result of the development of phototriangulation, the values of the direction cosines were obtained at the DPW "Talca".

Further, for the selected images, the rotation parameters of EO are calculated for the selected images according to the formulas (1)

$$\alpha = arctg\frac{a_3}{c_3}$$
$$\omega = \arcsin(-b_3)$$
$$\kappa = \mathrm{arctg}\frac{b_1}{b_2} \qquad (1)$$

where α - the longitudinal tilt angle of the image; ω - the transverse tilt angle of the image; κ - the swing angle of the image; a_3, b_1, b_2, b_3, c_3 - the direction cosines.

The following limiting values of the rotation parameters of EO are obtained

α, degrees	ω, degrees	æ, degrees
15,6	-6,2	-81,5

To determine the total tilt angle of the image α_p from the known rotation parameters of EO, the author L.A. Gavrilova derived the formula (2).

$$\cos\alpha_p = \frac{\cos^4\alpha + \cos^4\omega}{2\cos\alpha * \cos\omega} \qquad (2)$$

The maximum tilt angle αp of the image was 16.4 ° in this experiment.

On the basis of the obtained tilt angles αp, the geometric properties of the image are analyzed according to the known photogrammetry formulas.

Determination of the difference in the scale of the image due to its tilt angle

With these parameters of survey, the scale difference is 1: m = 1: 6500 in the central part of the image, at the edges of the image 1: m min = 1: 8400; 1: m max = 1: 5900; The relative multiscale is 38%.

The determination of the displacement of the image points caused by its tilt angles αp

The maximum displacement for a point located on the principle line and as far from the isocenter is 2, 8 mm in the scale of the image.

Determination of foreshortening of directions on an off-nadir image

The maximum foreshortening of the direction to the points located in the corners of the working area of the image is 5.9 °.

Determination of foreshortening of areas on an off-nadir image

For f = 30.87 mm; H = 200 m; αp = 16.4° at the edge of the photo on the principal line, the relative foreshortening of areas is = 7%.

Displacement of the image points due to the combined effect of the terrain and the tilt angle

For points on the earth's surface with a height difference up to 15 meters, displacement on the off-nadir images is 4 mm.

For multi-storey buildings (height 60 m), the displacement of the roof points relative to the base was 7.5 mm.

Features of the geometry of the images caused concern in the loss of accuracy in the photogrammetric processing of images.

In order to test the possibility of orthorectification of images for the creation of an orthophoto, experimental studies were performed. The creation of the orthophoto was carried out at two digital photogrammetric workstations – «Talca» and «Photomod». The technology of orthophotomap creation was carried out according to the traditional scheme. The total accuracy of the full range of work was evaluated based on the final result.

To assess the accuracy of the orthophotomap within its limits, 30 uniformly located control points were chosen.

The geodetic coordinates of the control points were obtained on site by GPS-equipment and an electronic total station with an accuracy of 1 mm. Differences in the geodetic and photogrammetric coordinates of the control points are used to determine the RMSE of photogrammetric transformations when an orthophotomap is created.

The root mean square error of the planned position of the orthophoto points was 0.37 m.

$$M_{X,Y} = 0.37 \text{ m}$$

The accuracy of the created orthophotomap meets the requirements of the normative documents, the RMSE for determining the coordinates of the control points does not exceed in plan 0.3 mm for the scale of the created orthophoto 1: 2000.

Analysis of the technology of creating orthophotos from images obtained from UAV determined the advantages and disadvantages associated with the features of the production of such aerial photography.

The main advantages of survey with UAVs before classical aerial survey are:

- compactness and removable modules;
- the possibility of starting and landing in a limited area;
- no need for special airfields;
- the possibility of low-altitude aerial survey (below the cloud boundary);
- simplified scheme for obtaining permits for flights;
- mobility and efficiency in operation;
- noiselessness;
- ease of maintenance;
- saving material and time, etc.

Survey with UAVs is particularly effective when you need to take photos of small areas with a small height.

Essential disadvantages of using UAVs in aerial survey are:

- the images have large tilt angles, which cause the appearance of "dead zones" in areas with high-rise buildings, as well as significant scales of images that complicate their stereo-photogrammetric processing;
- vibration caused by aerodynamic characteristics of UAV and flight conditions, reduce the visual properties of the images. As a result of the experimental work, the following features of the images of urban areas obtained from UAV, their geometric and visual properties, photogrammetric processing:
- significant tilt angles of the images lead to a decrease in the longitudinal and transverse overlap of stereopairs. As a result, there are difficulties in the relative orientation of the images during the selection of tie points;
- shadows falling from high buildings, greatly complicate the finding of photogrammetric points;
- the images show significant displacement of the images of the roofs (so-called "blockages") of multi-storey buildings from the point of nadir, resulting in the formation of geometric shadows ("dead zones"). This feature of the images determines the selection of working areas on the images for the subsequent exclusion of "dead zones";
- the difference in scale within the image leads to local disturbances of the stereo model, which makes it difficult to construct digital terrain models in a stereophotogrammetric way. This, in turn, causes difficulties in the orthorectification of images of urban areas.

In the following experiment, a version of orthophotomapography based on UAV images using exterion orientation elements, determined in flight (without image georeferencing), and the possibility of using them for monitoring of properties was considered.

In the experiment we used images obtained from UAV Irkut-10 on the territory of Dmitrovsky District, Moscow Region. The aerial survey was performed in a scale of 1: 32 000 by a digital calibrated SIGMA-DP2S camera with a focal length of 24.2 mm.

The images were attached to the .KLM format, in order to be displayed in the Google Earth program, as well as the exterion orientation elements defined in the flight.

PHOTOMOD 6 Lite was used for photogrammetric processing of images for the purpose of orthomosaic plotting. Lite version of the program can handle a relatively small number of images (no more than 40). Therefore, images were initially selected for small groups of one or more land plots. The main criterion for selection was the availability of information on land plots on the Public Cadastral Map: cadastral number, area.

Information about the terrain is also needed for creating an orthophoto. For the construction of a regular DEM, the grid spacing was calculated by the formula 3 derived by L.A. Gavrilova.

$$L = \frac{\sqrt{2} \times \delta_h \times f \times \text{М}_{пл}}{r_n \times tgv} \quad (3)$$

where δ_h - is the permissible displacement for the relief on the created plan (0, 3 mm), f - is the focal length of the camera (24.2 mm), M - is the denominator of the scale of the created plan (M = 5000), r_n - is the maximum distance from the nadir point (12,43 mm), tgv - is the maximum slope in the treated area (tgv = 0.20).

Some settlements (5) of the Dmitrovsky district were selected for formation orthophoto mosaic.

Land plots were found in the automated information system "Unified state property register ". Coordinates of the turning points (in the coordinate system of the MSC-50) of the selected land plots were obtained from the "Unified state property register ".

In the course of photogrammetric processing an orthophoto mosaic (Figure 3) of scale 1: 5000 was obtained (the merging of orthophotos was performed in the program PHOTOMOD 6 Lite GeoMosaic)&

The service GIS component MapInfo is used in the Unified state property register to display the graphic cadastral information and its processing. Therefore, to obtain the coordinates of the turning points of the boundaries of the land plots, the orthophotomaps obtained were saved in the "MapInfoTable" format. The processing was done in the MapInfo demo. The total number of images in the processing is 94, orthorectificated images are 45.

For the turning points of the boundaries of the land plots, measurements of the coordinates on the orthophoto are made and an accuracy estimate is made in comparison with the data from the Unified state property register.

The root-mean-square error of the planned position of the turning points of the boundaries of the land parcels is calculated by the Gauss formula:

$$m = \sqrt{\frac{[\Delta]^2}{n}}. \quad (4)$$

And m was 1.8 m in our experiment.

The results of the assessment of the accuracy of the coordinates of the turning points of the boundaries of land plots make it possible to assert that the obtained orthophotomaps can be used for the purposes of monitoring land parcels classified as:

- to agricultural lands (with the exception of land parcels classified as agricultural land and provided for personal subsidiary, summer cottage, truck farming, gardening, individual urban or individual housing construction);
- to the lands of the forest fund,
- to the lands of the water fund,
- to the reserve lands.

A B

Figure 3. Orthomosaic:
A – orthophoto image, constructed in the program PHOTOMOD 6 Lite GeoMosaic;
B - location of ortho images in the Google Earth program

In conclusion, it should be noted:

- expediency, profitability and use of unmanned aerial vehicles for the aerial survey in the management of cadastre and monitoring of properties;

- the need for precompute calculations of the parameters of aerial photography taking into account the technical characteristics of the aircraft and the camera;

- further photogrammetric processing and interpretation of images to create orthophotomaps and other cartographic products of the specified accuracy requires qualified training of specialists in the field of aerial photography, photogrammetry and interpretation.

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МОНИТОРИНГ ОБЪЕКТОВ НЕДВИЖИМОСТИ ПО МАТЕРИАЛАМ, ПОЛУЧЕННЫМ С БЕСПИЛОТНЫХ ЛЕТАТЕЛЬНЫХ АППАРАТОВ

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Аннотация: *В дистанционном зондировании земной поверхности беспилотные летательные аппараты являются одним из видов носителей съёмочной аппаратуры. Применение БПЛА становится эффективным по сравнению с использованием пилотируемых летательных аппаратов при необходимости срочного обновления электронных карт, а также мониторинга происходящих изменений на небольших рассредоточенных в пространстве территориях. В этих случаях применение пилотируемой авиации будет приводить к неоправданным затратам, что нецелесообразно с экономической точки зрения. Кроме того, отсутствие благоприятных погодных условий нередко приводит к срыву выполнения аэрофотосъёмочных работ в намеченные сроки, когда АФС наиболее эффективна и целесообразна. Применение одних лишь наземных методов сбора информации и выполнение геодезических съёмок также ведёт к удорожанию работ, а в некоторых случаях к невозможности их проведения (отсутствие доступа на охраняемую территорию, в частные владения и т.п.). В этих условиях использование легко доставляемой к объекту съёмки, дистанционно управляемой авиамодели, оборудованной необходимой съёмочной и управляющей аппаратурой, позволяет оперативно выполнять аэрофотосъёмочные работы даже в случае отсутствия устойчивых погодных условий, необходимых для выполнения традиционной АФС. Для применения БПЛА достаточно кратковременного «окна» хорошей погоды. Кроме этого, возможность съёмки с малых высот позволяет её проведение при низкой сплошной облачности. Использование БПЛА эффективно при съёмках линейных объектов, при инвентаризации и кадастре объектов недвижимости, а также для получения оперативной информации при чрезвычайных ситуациях.*

Ключевые слова: *Аэрофотосъемка, БПЛА, дистанционное зондирование, мониторинг земель, точность.*