

Application of terrain stereomodels for decoding and determining the coordinates of characteristic points for real estate objects in complex cadastral works

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Abstract

The article considers applied aspects of using a photogrammetric method of determining the coordinates of cadastral registration objects by way of creating terrain stereomodels. The purpose of the study is to evaluate the advantages of using stereo models based on the proposed technological solutions that expand the capabilities of the photogrammetric method in complex cadastral works. The obtained results of the study justify the expediency for expanding the technological capabilities of the photogrammetric method as for collecting and processing geospatial data in the field of cadastral activity, methodological recommendations to organize production activities while the implementation of complex cadastral works and improving the quality of spatial data included to the state real estate cadastre. The solutions suggested are justified to reduce the future possible errors while decoding, due to the additional use of angles with reliable unambiguous interpretation of characteristic points. In order to improve the technology of complex cadastral works, the study determines the values of coordinates discrepancy obtained by the photogrammetric method and control measurements, as well as the types of “fixing” characteristic points calculating the most probable mean square errors in coordinates. The research also provides recommendations on the value for overlaps of images and accuracy criteria to prepare initial oriented images in complex cadastral works.

1 Introduction

According to the Russian Federal Service for State Registrations, Cadastre and Cartography (Rosreestr) for 2021, the boundaries of more than 23 million land plots have not yet been determined; a significant number of previously recorded capital construction projects do not contain information on counter coordinates. These indicators prove the need to further develop the system for recording information about real estate objects by means of increasing the efficiency of cadastral activities, improving technologies and methodological support for their application. The development and updating of applied programs within the mechanism of complex cadastral works proposed by Rosreestr can accelerate the receiving of updated information about previously recorded objects, and the use of photogrammetric methods for processing Earth remote sensing data solves the problem of carrying out cadastral works for significant territories.

The study of options for applying remote sensing results proves the inexpediency in using the results of satellite imagery to carry out complex cadastral works for built-up areas. Thus, the authors in [1] point out in their study that the obtained stereo images of Worldview-3 provide a planned accuracy of about 2.16 m (mean error) and 0.55 (std. error).

As far as the study [2] is concerned, the best pairs of results STDV (Dxy) 0.63, RMS (Dxy) 1.7 m were obtained. Also, the Russian satellite constellation "Resurs-P" does not provide the required result in order to carry out cadastral works for built-up areas [3], which are characterized by a mean square error¹ in determining the characteristic points of terrain objects equal to 0.1 m.

Certain experience shows that for relatively small areas, it is most effective to use the results

of remote sensing implementing a complex of photogrammetric works with the use of the unmanned aircraft system (UAS). A further task for cadastral purposes is to clearly identify the characteristic points of the objects to be considered on images.

In this regard, the methods of creating terrain stereomodels are quite promising, which, as noted by Yambaev Kh.K. et al. in [4], allow a sufficient number of views and points on vertical and inclined elements of the object model for their confident identification, which guarantees a fast, not at all expensive and, what is most important, reliable way to decode the characteristic points of terrain objects.

In order to develop the variability of the areas for stereomodels use it is necessary to apply the results of scientific research, which generalize the practice of their implementation and form the optimal technological sets of solutions that provide fast collection, coordination of objects, analysis and data management [5].

Such solutions should make the best use of available technologies and data about the territory to meet the needs of the state real estate cadastre, as well as for various types of objects to be accounted, as consider Toschi I. et al. in [6], to generalize practices, methods and technologies for cadastral works. The analysis of the influence of stereopairs quantity, as shown in [6], proves that there is always data redundancy, which increases the reliability of coordinates determination when using stereophotogrammetric constructions.

In this regard, one of the urgent scientific problems is to provide the methodology of the best interpretation of characteristic points for objects to be accounted by means of determining the optimal solutions for the quantitative set (redundancy) of pairs of images in the design of complex cadastral works and their typification.

¹ Order of the Federal Service for State Registration, Cadastre and Cartography dated October 23, 2020 No. P / 0393 "On approval of requirements for accuracy and methods for determining the coordinates of characteristic points of land plot boundaries, accuracy requirements and methods for determining the coordinates of characteristic points of the contour of a building, structure or construction in progress on a land plot, as well as requirements for determining the area of a building, structure, premises, parking space". (in Russ).

2 Methods and materials

The research was carried out on the basis of unmanned aerophotosurveying. Aerophotos were obtained using SonyRX1 and RX1RM2 cameras with an area pixel projection size of 0.05 m with line overlaps and side overlaps of 60–70%, which meets the established requirements.

Aerophotosurveying was conducted on the territory of 23 municipal structures of the Republic of Bashkortostan, Izhevsk (Udmurtia, Russia) and the Kaliningrad region. The total area covered by 677.279 aerophotos was 396.750 hectares, and 1.602 calculations of the coordinates of control points were made during photogrammetric processing of images. The stereophotogrammetric complex was used at work, including a polarization-type stereo monitor SM1 and a digital photogrammetric system PHOTOMOD.

The information of the Unified State Cadastre of Real Estate about 416 land plots and 288 capital construction projects has been analyzed. Surveys and control measurements were carried out using geodetic equipment to achieve the highest accuracy in determining the location of the boundaries and contours of objects.

The studies analyzed the excess of the permitted values for the discrepancies in the coordinates of the characteristic points of real estate objects, obtained during complex cadastral works using the photogrammetric method and measurements based on the results of geodetic control.

The main criteria to evaluate the accuracy when using the initial aerophotos and the results obtained were:

- the projection size of a pixel on the ground for aerophotos - 0.05 m²;
- the size of the mean square error in determining the coordinates of the characteristic points for the boundaries of land plots¹ - 0.10 m.

The conducted accuracy control included the

following processes:

- geodetic measurements and obtaining of coordinates of control points;
- stereophotogrammetric measurements and obtaining of coordinates of control points;
- comparative analysis of the results obtained.

Moreover, there had been a research to establish the influence of line and side overlaps values of aerophotos on a number of angles of a unique “point”, an assessment of the technological efficiency while using terrain stereomodels according to the types of characteristic points of real estate objects.

3 Results

The coordinates of the characteristic points for the boundaries of land plots and capital construction objects in settlements are mostly calculated using traditional geodetic, satellite geodetic, combined measurement methods. Once unmanned aerial systems are put in practice of aerophotos and the improvement of the regulatory framework in the field of cadastral activities open up opportunities for the widespread use of the photogrammetric method when carrying out cadastral work for different types of land in settlements and horticultural associations.

Based on the results of the comprehensive cadastral work carried out, the control measurements showed the following discrepancy (Fig. 1) in the coordinates determined by the terrain stereo model and the results of geodetic measurements (reference).

Geodetic determination of the coordinates of control points was performed by the method of satellite geodetic measurements (determinations) and by the method of tacheometric survey. Satellite geodetic measurements were performed in a differential way in a static mode.

² State Standard R588544-2020. Photogrammetry. Requirements for the creation of oriented aerophotos for the construction of stereo models of built-up areas. Order of the Federal Agency for Technical Regulation and Metrology dated May 15, 2020 N204-st). (In Russ.)

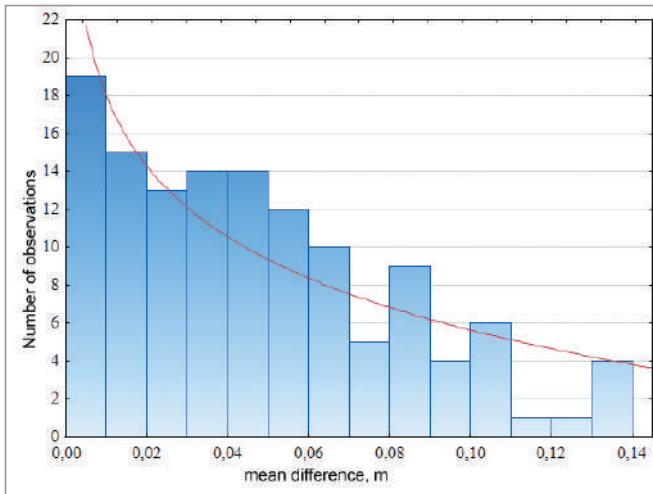


Fig. 1. Diagram of the distribution of the discrepancy values between the coordinates obtained by the photogrammetric method and the method of control measurements

The average value of the discrepancy was 0.052 m, the standard deviation from the average meaning was 0.034 m. In accordance with the obtained possible theoretical distribution of the discrepancies (Fig. 1), it was determined that 82.35 % of the discrepancies are within 0.086 m, so 17.65 % of the characteristic points exceeded the standard deviation. Considering the fact that the data was prepared in accordance with regulatory requirements², the problem of exceeding the values of discrepancies with control measurements is their fuzzy interpretation.

Applied research shows that the best technology for decoding characteristic points of real estate objects, and therefore determining their coordinates, is a stereophotogrammetric method, which consists in using several stereopairs of aerophotos and creating stereomodels of the territories based on them. It should be noted that a distinctive feature of stereo models is the fact that a characteristic point can be displayed from several angles. In practice, stereo terrain models are created from pairs of photographs with different ratio of line and side overlaps.

When using a photogrammetric method, a number of factors should be distinguished that affect the quality of identifying the characteristic points of objects of the cadastral work, which is a significant technological process due to the absence of a cadastral engineer on the location:

- the type of property and the terrain conditions (for example, recognizing a concrete fence is more reliable than a wooden fence in tall grass);
- the image quality of the real estate object on aerophotos (“blurred” images, the hiding of the characteristic point under the “blockage” of a house wall, etc. make it difficult to conduct measuring). Therefore, the assessment of the necessary redundancy of the characteristic point observation options allows conducting measurements in the best visibility conditions (select images for measurement without “blurring” the image; to measure a point under the roof overhang, select stereo models with an “open” facade, etc.). Accordingly, the issue of justifying the redundancy of images, including, possibly, those of different times, as indicated in the work [7] by Chibunichev A. G., Zharova N. E., when determining coordinates, refers to the issue of examining the analytical generalization in the form of guidelines.

Taking into account the values (Fig. 1) obtained in the course of the study, the task considered the use of different angles of the decoded point for its clear identification. In the applied aspect, the following sequence of photogrammetric determination of the coordinates of characteristic points was proposed:

- a) identify the characteristic point on all stereopairs to which it falls;
- b) choose the best stereopairs for observations;
- c) determine the coordinate of the characteristic point in two stereopairs with the most reliable point identification.

If a characteristic point is placed the corner of a fence or a building, and it is not clearly defined by its basis, then it is necessary to perform one of the following options:

- apply the method of geometric constructions which consists in drawing straight lines along the visible sections of a fence or a building to obtain the intersection point. The coordinates of the intersection point will be the coordinates of the characteristic point of the land plot or the object of capital construction;
- take measurements not along the basis, but at a clear observation height (applicable if the angle of the fence is above ground level, and the building can be seen confidently);

- the discrepancy between the coordinates obtained in two stereopairs should not exceed 20.1 m. Calculate the average value of the coordinates of the characteristic point. According to the results of the work performed (Table 1), while areal aerophotosurveying with line overlaps and side overlaps of 60% (standard conditions for manned aerophotosurveying), it was established that any point of the location is depicted on 2–5 images. With an increase in the line overlap to 70%, the number of images for each point of the location ranged from 3 to 11.

In theory, this makes it possible to compose up to 36–66 pairs of images. Of these, pairs that form stereomodels with the most comfortable stereo effect are of practical interest.

As a rule, these are stereomodels composed of images of the same route. There are, on average, four with 60/60% overlap and six with 70/60% overlap. Digital aerophotosurveying and the creation of a stereophotogrammetric model, aerophotosurveying parameters are given in Table 2. The characteristics of spatial phototriangulation are presented in Table 3. According to the established norms¹, the creation of stereomodels is carried out using oriented images obtained with an average error in the plan of not more than 0.06 m. Considering the ratio of the mean and root mean square error equal to 1.4 RMS, will be 0.084 m. This value, as a criterion, was used in assessing the quality of the photogrammetric work in question³.

Table 1. Number of stereopairs per point depending on overlap values

Stereomodel type (aerial overlap)	Number of stereopairs with the characteristic point displayed	Number of stereopairs with confident measurement of the characteristic point	Mean square errors of measurements, m
60/60 %	2–5 (4 in average)	1–3 (2 in average)	0.052
70/60 %	3–11 (6 in average)	2–5 (3 in average)	0.033

Table 2. Aerophotosurveying parameters of Izhevsk (Russia)

Current characteristics	Value of technical characteristics
Aircrafts	Unmanned aerial system "Geoscan-201"
Aerophotosurveying altitude	300–350 m
Terrain pixel projection size	5,0 cm
line overlap	70%
side overlap	60%
Digital cameras	<i>Sony DSC-RX1, DSC-RX1RM2</i>
Focal length	35 mm
Matrix size	5 304 x 7 952; 4 000 x 6 000 pixels
Terrain pixel size	4.5; 5.0 cm

³ Instructions, standards and rules in geodesy and mapping (GKINP) - 02-033-79. Instruction for topographic survey at scales 1 : 5000, 1 : 2000, 1 : 1000, 1 : 500. Moscow. *Nedra*, 1982. 159 p.

Table 3. Characteristics of spatial phototriangulation

Type of the point	Quantity of points	Mean errors in the plan, m	Maximum errors in the plan, m	Quantity of points	Maximum errors in height, m
Control landmarks	27	0.03	0.04	27	0.2

The coordinates of all control points were determined by the stereophotogrammetric method. As suggested in the research, the definitions were carried out in two ways using PHOTOMOD6. Figure 2 shows examples of control points of various types (based on the materials of the work performed), so these are landmarks.



Fig. 2. Examples of outline control points

After carrying out stereophotogrammetric measurements between the methods, the discrepancies in the position of the control points were calculated. The mean of the discrepancy was 0.0339 m (standard deviation 0.018), and the confidence interval for the mean, at the 95% possibility, was 0.015.

These indicators show the expediency of redundancy of stereopairs and the effectiveness of the proposed solutions due to a significant reduction in the extreme values of errors associated with decoding.

It has been established (Table 3) that the redundancy of images can be taken at the level of 70/60% of the overlap of images, which makes it possible to confidently obtain at least two foreshortenings of one characteristic point and reduce the amount of aerophotosurveying, for example, used in the study by Shih-Hong Chio et al. [8].

In order to improve the technology of complex cadastral works, attention is paid to the distribution of the control discrepancies according to the types of “fixing” characteristic points. Based on the results of the grouping carried out regarding the values of the average values of the discrepancy, the following classification of the types of characteristic points was proposed (Fig. 3): the corner of the building of one-floor buildings, from 2 to 5 floors, from 5 floors or more, metal and wood fence, concrete fence.

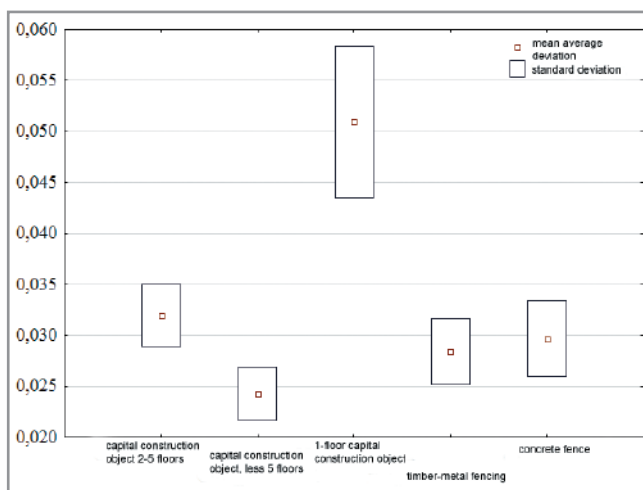


Fig. 3. Average value of control discrepancies for characteristic points of different types, m

Average errors in control measurements were obtained, which ranged from 2.42 to 5.09 cm, depending on the type of the object (Fig. 3). All of them are less than permissible² 0.06 m, which makes

it possible to confidently recommend this technique for stereophotogrammetric determination of the coordinates of characteristic points and makes it possible to optimize measures to control the work performed at the production site.

4 Discussion

The proposed technological solutions expand the possibilities of using the photogrammetric method for determining the coordinates of the characteristic points for the boundaries and borders of real estate objects. At the same time, the accuracy of the planned coordinates of the characteristic points is ensured, which is characterized by the root-mean-square error, that should not exceed 10 cm.

Despite the fact that it is advisable to carry out this type of work for large areas, the conclusion by Shih-Hong Chio et al. in carrying out a similar work for urban areas of Taiwan [8] are worth being agreed to. This group of researchers notes that the obtained analysis of the cadastral state of lands, obviously, gives more evidence of the territories and can have a multifunctional application.

Also, the conclusions and materials presented in this research can be used for further studies in the search of the optimal combinations of overlapping images, depending on both the degree of urbanization of territories and various purposes of aerophotosurveying.

5 Conclusion

Image processing can mainly result in stereomodels - a three-dimensional high-precision image of the location obtained from the best stereopairs, which increases the objectiveness of the results of the photogrammetric method for determining coordinates.

The proposed sequence of technological operations makes it possible to reduce the probability of errors during the decryption

by $\approx 17\%$, due to obtaining from two to five angles - with reliable unambiguous recognition of characteristic points.

As a result of the research performed, the following conclusions can be drawn:

1. When determining the coordinates of characteristic points of real estate objects, the photogrammetric method for determining coordinates with an excessive condition for using stereopairs (at least two) is quite promising, so

finally it is possible to avoid the effect of “fuzzy” interpretation, improve the quality of data entered into the real estate cadastre.

2. The proposed solutions for stereophotogrammetric determination of the coordinates of characteristic points of real estate objects and typification of characteristic points can be the basis of a feasibility study and design of complex cadastral works.

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