КАРТОГРАФІЯ І АЕРОФОТОЗНІМАННЯ

CARTOGRAPHY AND AERIAL PHOTOGRAPHY

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I. KOLB

Department of Photogrammetry and Geoinformatics, Lviv Polytechnic National University, 12, Bandery Str., Lviv, 79013, Ukraine, tel. +38 (032) 2582616, e-mail: post i_kolb@ukr.net

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METHODS OF CREATION AND PRACTICAL APPLICATION OF MASK-MAPS OF HIGH-LEVEL TERRAIN OBJECTS AT ORTHOTRANSFORMATION OF DIGITAL AERIAL PHOTOGRAPHS

Aim. To develop and accomplish an experimental testing of the method of creating a mask map of high-level terrain objects. **Methodology.** On the basis of the cross-correlation method, it is proposed to carry out the estimation of the similarity of orthophotos that have a mutual spatial overlap. The comparison of the left and right images takesplace in pixels, for pixels with the same spatial coordinates X and Y, and therefore, there is no need to organize the movement of the search bar and to search for the corresponding points as such. It also removes the limit on the size of the image – the standard. In addition, the relatively small cross-correlation sensitivity to the differences in the illumination of the scene is very important for the choice of the correlation coefficient as a measure for the comparison of images. Taking into consideration the perspective deformations of images of high-level terrain objects it is expected that the number of pixels with negative comparison is significantly higher for regions with images of such objects. The overall picture throughout the study is a map-mask of high-level terrain objects. Such a map can be formed with the help of geoinformation modeling of polygonal objects, which outline zones with a high compaction of pixels with a negative comparison result. **Results.** The considered method of creating a map-mask of high-level terrain objects provides a possibility of obtaining important information about the quality of the digital topographic surface model used for orthotransformation of aerial photographs. The revealed effect of compaction points with a negative result of the mutual comparison of orthogonal images by the cross-correlation method allows to identify and establish the spatial location of high-level terrain objects such as roofs of buildings, fences, power lines, crowns of trees, and shrubs. **Practical meaning.** An example of map-mask application of high-level terrain objects for orthoimage stitching is given.

Key words: Aerial photography, orthophototransformation, orthophotoplan, orthoimage stitching.

Introduction

One of the most common products of digital photogrammetry are orthophotomaps and orthophotographs. The creation of such products takes place with the use of terrain images that are received through a variety of aerial and space shooting systems as well as geospatial data necessary for digital simulation of the relief of the captured area and georeferencing imagery.

The technological process of creating an orthophotoplan from digital aerial photographs is based on the consistent implementation of a number of analytical actions related to the redesign of elements of georeferred photographic or scanned images of a given topographical surface. At the same time, each image of the photogrammetric unit allows the formation of an orthoimage – a virtual digital image of the terrain of a given spatial distinction in an orthogonal (parallel to the *XY* plane of the external geodetic coordinate system where the topographic system is determined and in relation to which the image orientation is made) projection. Further orthoimages are stitched in a single raster image of the area within the limits defined by the project conditions of topographic survey of the territory [Dorozhynskyy & Tukai, 2008].

When creating orthophotoplans, two types of digital surface models are used fundamentally: the digital model of the visible surface (English: DSM) and digital model of surface relief (DTM). The result of the orthophototransformation based on the

DSM model is the so-called “true orthophoto” which is an orthogonal image of the territory with no visible deformations. When using DTM model, the purpose is to obtain an orthogonal image of the terrain at the level of the relief, while images of high-level objects on the orthophoto remain with perspective deformations. However, in the case of using DSM model, the correct orthoimage stitching into a mosaic is not guaranteed [Chen Q., Sun M., Hu X., & Zhang Z., 2014]. Therefore, it is appropriate to discuss the need to control the quality of the two sets of input data, namely:

- Accuracy of georeferencing of images of a photogrammetric unit or more specifically for aerial photography – accuracy of determining the elements of external orientation of images;
- Accuracy of the digital model of the topographic surface.

The control of the first component is a well-studied problem of analytical photogrammetry and occurs at the stages of phototriangulation, inverse photogrammetric serif or determination of parameters of projection transformations in georeferencing of space images [Dorozhynskyy, 2015].

The control of the second component can be carried out a priori on the basis of comparison of DTM parameters with the requirements of sectoral regulatory documents, the source of which is the analysis of the analytical link of coordinates of location points with the coordinates of the corresponding point of the picture [Bielski, Grazzini, & Soille, (2007); Kadnychanskyy, 2010]. When it is required to create a “true orthophoto”, this approach to evaluation cannot be used, since topographic instruction does not mention the quality of reflection in the model of high-level terrain objects. In the a priori assessment, an analysis of the methodically achievable accuracy of the interpolation of heights for the pixel centers created by the orthophoto under the available discrete DTM is also used [Kadnychanskyy, 2010]. However, as a rule, it is impossible to obtain reliable DMT quality assessments due to the presence of many methods for determining the DTM structure, the methods used for interpolation of heights and the variable surface morphology.

The second problem of controlling orthotransformation is the assessment of the accuracy of the received orthophotoplan. The precursor estimation of the accuracy of the orthophotoplan on the reference points and the faults of joining the linear terrain objects reflects the total effect of the two components described above and does not answer the important question for practitioners which of these components makes a greater contribution to the revealed errorand, accordingly, there is no possibility to correct that or another set of data. This required significant time to find errors in the total volume of data and then to repeat the whole technological process. In this way, it is stated that the quality control of the digital model of the topographic surface used to create orthophotoplans is an urgent problem.

Aim

The choice of the type of digital surface model is performed in accordance with the requirements of the specification of a particular mapping project. However, in both cases, it is useful to distinguish zones to place high-level objects, for example, to prevent the passage of orthophoto lines through the image of elevated artificial structures and crowns of trees. In addition, this information can be used to assess the degree of closure of the territory, the calculation of “dead” zones. This information may particularly be useful for detecting and spatial localization of errors in the input digital surface model. Thus, it will be possible for the input data operator to perform a point adjustment only at certain points and therefore to ensure the quality without any unnecessary time consumption (hence the visual quality of the terrain display and the geometric accuract of the orthophotoplan created).

Methods

It is stated that it is possible to perform the quality control used for orthotransformation of aerial photographs of a digital surface model using two approaches. The first approach is to implement the computer 3D stereo reconstruction similar to the dense image matching [Remondino, Spera, Nocerino, Menna, Nex, & Gonizzi, 2013]. This approach is costly in terms of computing time and has certain limitations, such as the uncertainty of dead zones, the impossibility of obtaining a model on a low contrast, little contour of images, the noise of the resulting surface model, sensitivity to changing landscape lighting conditions and other variables known in photogrammetric practice [Baltsavias & Käser, 1998; Kerschner, 2000]. The second approach is to analyse the similarity of stereopair images formed by orthotransformed images [Georgopoulos & Skarlatos, 2003]. This approach seems to be more perspective to apply in practice, since a photogrammetric model formed by orthogonal images having a mutual overlap, will be free from perspective deformations in areas with proper quality of DTM and will save the deformations in areas where such quality is inappropriate. The displacement of images of the corresponding points of such stereopair can be calculated from the known formulas for the images of the central projection [Dorozhynskyy & Tukay, 2008]:

$$\delta_h = \frac{rh}{H} \cdot \frac{1-\frac{r}{2f}\cdot\sin 2a_0 \sin\varphi}{1-\frac{r}{2Hf}\cdot\sin 2a_0 \sin\varphi} \qquad (1)$$

where *r*, *φ* – polar coordinates of a point in a sytem with a start at the point of a nadir; h – point excess above the mid-sagittal plane; α_0 – inclination angle of the plane of aerial photo; H – height of photographing; *f* – focal length of the aerocamera.

For a horizontal image of the central projection (in $\alpha_0 = 0$)

$$\delta_h = \frac{rh}{H}. \qquad (2)$$

It should be noted that these formulas are obtained for images of the central projection, and orthoimages are represented in parallel projection. It is obvious that in case of orthotransformation, the deformation of the image cannot be eliminated at the points for which the input DTM sets the false values of the heights. Therefore, the formula (2) actually describes the residual deformation of the image at a given point, which was caused by an error in setting the height in DTM. Therefore, the known method of DTM correction based on this formula [Georgopoulos & Skarlatos, 2003] has obvious weaknesses in determining the true height of the photographic point over a specific location point and in determining coordinates r, because the position of the image point was corrected when the analytical horizontal image was received.

It must be also noted that DTM is assigned a continuous coating and includes the heights values of the relief for the locations of high-level objects (under the houses and crowns of trees). For such terrain points, you should expect a maximum dissimilarity of the corresponding images on orthophotos that have spatial overlap.

Analysis of similarity of images is widely used in digital photogrammetry. Measures of similarity determine the degree of similarity between the images of the intensity of two images [Goshtasby, 2005]. The choice of the similarity degree of images depends on their modality. Typical examples of these similarity measures of images are cross-correlation (or mutual correlation), mutual information, the sum of the squares of the intensity differences, and the ratio of the image uniformity. The degree of mutual information and normalized mutual information is the most popular similarity measure when comparing multimodal images. Cross-correlation, the sum of the squares of the intensity difference and the uniformity of the image ratio are commonly used to register images of the same modality. As it is supposed, cross-correlation may be an effective measure to compare orthophotos, as in this case the comparison of the left and right images occurs in pixels, for pixels with the same spatial coordinates X and Y. Therefore, there is no need to organize movement of the search bar and to search for the corresponding points as such. The limit on the image size – the standard- is also removed. In addition, the essential for choosing this measure for the comparison of images is its relatively small sensitivity to the differences in the illumination of the scene. If there are two orthoimages $I_L(n,m)$ and $I_R(n,m)$ having a zone of mutual reflection, then images of a specific terrain point *(x,y)* will be formed as fragments of images of size *w, l*. The function value of mutual correlation of these images will be determined by the formula

$$R_{I_L I_R}(x,y) = \sum_{i=x-\frac{w}{2}}^{x+\frac{w}{2}} \sum_{j=y-\frac{l}{2}}^{y+\frac{l}{2}} I_L(i,j) \cdot I_R(i,j) \qquad (3)$$

and the function values of autocorrelation of these images are determined by the formulas

$$R_{I_L I_L}(x,y) = \sum_{i=x-\frac{w}{2}}^{x+\frac{w}{2}} \sum_{j=y-\frac{l}{2}}^{y+\frac{l}{2}} {I_L}^2(i,j) \qquad (4)$$

$$R_{I_R I_R}(x,y) = \sum_{i=x-\frac{w}{2}}^{x+\frac{w}{2}} \sum_{j=y-\frac{l}{2}}^{y+\frac{l}{2}} {I_R}^2(i,j).$$

Then the normalised coefficient of mutual correlation of two points of the image *(x, y)*:

$$\rho_{I_L I_R}(x,y) = \frac{R_{I_L I_R}(x,y)}{\sqrt{R_{I_L I_L}(x,y) \cdot R_{I_R I_R}(x,y)}}. \quad (5)$$

If necessary, to ensure invariance to minor radiometric deformations, for example, a simple photographic deformations of the brightness of the form $I' = aI + b$ in formulas (3)–(5), deviations from the average brightness in the corresponding image are introduced instead of the brightness values directly.

As it is seen from formulas (3)–(5), unlike the traditional use of correlation comparison of images in photogrammetry, there is no need to organize spatial shift in the search field. The image sizes of the point *w, l* remain significant parameters.

It can be asuumed that with aerotriangulation, the orientation elements of the images are determined with sufficient accuracy. Then it is expected that a great number of negative correlations should be expected on sites where deformation of orthogonal images is not eliminated, primarily due to the incorrect setting of the height mark. On sites with correctly set heights, it is possible to get a certain number of negative matches because of the presence of small objects in the image, non-topographical objects, and the difference in scene lighting.

Thus, correlation of orthoimage coordination creates preconditions for obtaining a map-mask of high-level terrain objects. Such a map gives a clear idea of the degree of closure (in the topographical sense) of the territory and can be used to clarify the stitching lines of orthophotos into a mosaic and in solving other problems of digital photogrammetry

Results

Experimental investigation of the proposed method was carried out on the materials of aerial photography of the countryside with plain relief, partly covered with shrubs and woody plants. Photos with spatial resolution of 0.07 m were obtained with a full-size digital camera UltraCAM D with a focal length of 150 mm. The photos are provided with elements of extermal orientation as a result of aerotriangulation with the use of a dense backbone network. In orthotransformation, a digital relief model with a resolution of 1 m was used and the accuracy of the point height was ±0.15 m.

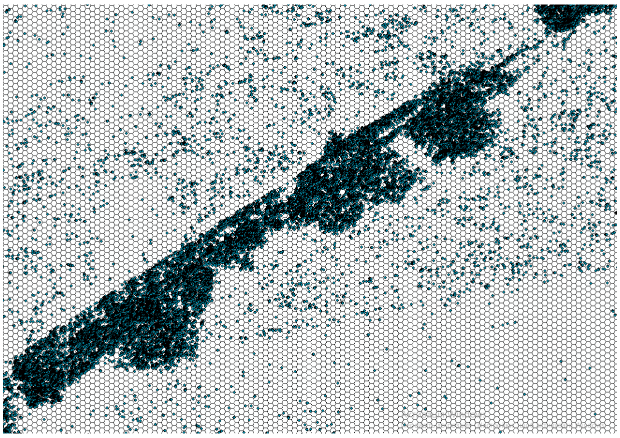
The results of the cross-correlation calculation are shown in Fig. 1. There are indicated only those points in which the correlation coefficient received negative values and according to our experiment conditions that indicates incorrect height mark settings in a specific point of terrain model.

a

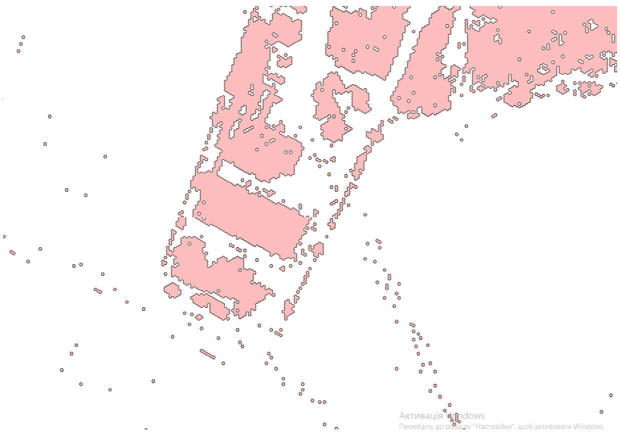
b

Fig. 1. The result of cross-correlation calculation for two digital orthophotos. Points denote pixels with negative correlation. Local compaction of points indicate presence of high-level objects

As it was noticed earlier and as it follows from Fig. 1, the number of points with a negative correlation is significantly higher for areas with images of high-level terrain objects. As an example, Fig. 1B shows this compaction, which describes the tree crown. The overall picture presents a map-mask of the high-level terrain objects on all studied area. Such a map can be formed as a set of polygonal objects that are in the high-compaction zone. Geoinformation analysis tools with a set of points in a hexagonal mesh can be used to obtain such polygons [Demianov & Savelyeva, 2010]. For the use in approbation of a set of aerial photos empirically established by threshold values of compaction of points with a negative result of cooperation, there are 6 points per cell area of 0.5 m^2. The map-mask of high-level terrain objects is the result of a threshold assessment and aggregation of the received cells into polygonal structures (Fig. 2).



a



b

Fig. 2. The result of evaluating the compaction of points with a negative correlation of brightness: a – partition of hexagonal mesh; b – map-mask of high-level terrain objects

An example of applying the map-mask described above is the refinement of orthophotographic stitching lines when creating an orthophotomosaic. As it follows from a large amount of publications in the special literature, as well as the author's own experience, this task is quite relevant in the practice of modern digital photogrammetry.

The reasons for the unwanted visibility of the stitched sites of separate orthogonal images are known and described in the literature [Baltsavias & Käser, 1998; Kerschner, 2000; Chen and all, 2014]. The tasks of optimizing orthoimmage based on the analysis of the field of brightness and surface models of the object are being solved. The main feature of almost all proposed implemented in industrial software for automatic stitching lines are focused on ensuring the maximum similarity of images in places of stitching by colour, tint and intensity. In some advanced algorithms a maximum of similarities of textures is provided and through them the desired stitching line passes. Sometimes such decisions contradict the requirements of classical photogrammetry as to intersection linear and polygonal terrain objects. [Bielski, Grazzini, & Soille, 2007]. However, without the DSM model, it is virtually impossible to automatically cross the areas where high-level objects are located. Attemps to adapt simplified vector models of big terrain objects cannot guarantee a proper result due to the complexity of forms and the innumerable number of variants of placing such objects on the ground [Li, Dong, Hu, Li, & Tan, 2018].

The above-mentioned procedure for obtaining a map-mask of high-level terrain objects can be applied with the assumption that it is not important to know the relative height of an object above the surface of the relief. It is important to detect only its presence in a certain area and make the stitching line pass around such a zone. In Fig. 3, is shown the result of an orthophoto stitching line in an automatic mode (red) and stitching line conducted by an operator of digital photogrammetric station in an interactive mode (blue).

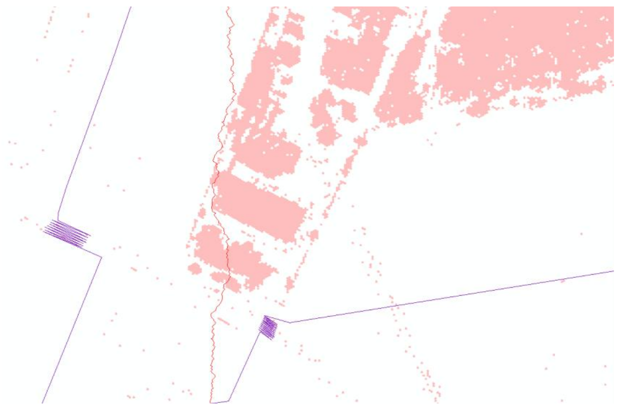


Fig. 3. Stitching lines of digital orthophotos

Obviously, in the first case, the visible disadvantage is the passage of the stitching lines through the image of high-level objects roofs of buildings and crowns of trees, which leads to the false reflection of these objects on the resulting orthophotoplan. An operator tries to get around all the potentially dangerous for quality cross-sectional areas, and often excessively deviates from the centre of the area of the mutual overlap of orthogonal images. In our opinion, it is optional to use a mask of high-level objects for a relatively minor correction of the automatically carried out stitching lines by the operator. This will minimize the processing time of the photogrammetric unit by the operator and ensure the high quality of the orthoplan.

The prospect of further research, in my opinion, is the search for methods of applying the mask – map of high-level objects of terrain to assess the level of closure of the earth's surface. The development of such a technique will allow to studiously choose technologies for large-scale topographic aerial survey, photogrammetric processing of aerial photographs and criteria for evaluating the created topographic products for specific areas.

Scientific novelty and practical significance

For the first time a method of creating a map-mask of high-level terrain objects was proposed on the basis of the analysis of digital orthotransformation technologies of aerial photographs. The proposed method for creating a map-mask of high-level terrain objects provides an opportunity to obtain important information about the quality of a digital topographic surface model used for orthotransformation of aerial photographs.

Conclusions

The effect of compaction points with a negative result of the mutual comparison of orthogonal images by the cross-correlation method allows to identify and establish the spatial location of high-level terrain objects such as roofs of buildings, fences, power lines, crowns of trees, and shrubs. An example of the use of such information is the implementation of orthoimage stitching.

REFERENCES

Goshtasby, A. A. (2005). 2-D and 3-D Image Registration for Medical, Remote Sensing, and Industrial Applications. John Wiley & Sons.

Baltsavias, E. & Käser, Ch. (1998). DTM and orthoimage generation – a thorough analysis and comparison of four digital photogrammetric systems. *IAPRS, 32, Part 4,* Stuttgart, FRG.

Bielski, C., Grazzini, J., & Soille, P. (2007). Automated morphological image composition for mosaicing large image data sets. *International Geoscience and Remote Sensing Symposium (IGARSS)*, 4068–4071. doi:10.1109/IGARSS.2007.4423743

Chen, Q., Sun, M., Hu, X., & Zhang, Z. (2019) An improved approach for generating globally consistent seamline networks for aerial image mosaicking. doi:10.3390/rs61212334. Available from:https://www.researchgate.net/publication/328227601_An_improved_approach_for_generating_globally_consistent_seamline_networks_for_aerial_image_mosaicking [accessed Apr 23 2019]

Georgopoulos, A., & Skarlatos, D. (2003). A novel method for automating the checking and correction of digital elevation models using orthophotographs. *The Photogrammetric Record.* 18. 156–163. doi:10.1111/0031-868X.t01-1-00015.

Kerschner, M. (2000). Twin snakes for determining seam lines in orthoimage mosaicking. *International Archives of Photogrammetry and Remote Sensing.* Vol. XXXIII, Part B4. Amsterdam 2000, 454–461

Li P., Dong Y., Hu Y., Li X., & Tan P. (2018). A method for the seamlines network automatic selection based on building vector. *ISPRS – International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences.* XLII-3. 909-913. 10.5194/isprs-archives-XLII-3-909-2018.

Remondino, F., Spera, M.G., Nocerino E., Menna F., Nex F., & Gonizzi B. S. (2013). Dense image matching: Comparisons and analyses. *IEEE Proc. Digital Heritage Conference.* Marceille, France, 2013. doi:10.1109/DigitalHeritage.2013.6743712.

Demianov, V. V., & Saveleva, E. A. (2010). Geostatistics. Theory and practice. Nauka.

Dorozhynskyi, O. L., & Tukai, R. (2008). Fotogrammetric. Lviv Polytechnic Publishing House.

Instruction on topographic scaling 1: 5000, 1: 2000, 1: 1000 and 1: 500. (HKNTA-2.04-02-98), Order of the Main Department of Geodesy, Cartography and Cadastre under the Cabinet of Ministers of

Ukraine. No. 56 dated 09.04.98. (in the wording of 27.07.99)

Kadnychanskyi, S. A. (2010). Substantiation of the requirements for the digital elevation model for orthophototransformation of aerial and satellite images. *Yzvestyia vysshykh uchebnykh zavedenyi heodezyia y aэrofotosemka*. 5, 49–54.

Dorozhynskyi, O. L. (2015). Mathematical models of analytical and space photogrammetry. Lviv Polytechnic Publishing House.

Chybunychev, A. A. (2002). Construction of digital orthoimages taking into account the heights of artificial structures. *Yzvestyia vysshykh uchebnykh zavedenyi. Heodezyia y aerofotosemka*. 6, 76–81

І. З. КОЛБ

Кафедра фотограмметрії та геоінформатики, Національний університет «Львівська політехніка», вул. С. Бандери, 12, Львів, 79013, Україна, тел. +38(032)2582616, ел. пошта i_kolb@ukr.net

СПОСІБ СТВОРЕННЯ ТА ПРАКТИЧНЕ ЗАСТОСУВАННЯ КАРТИ-МАСКИ ВИСОКИХ ОБ'ЄКТІВ МІСЦЕВОСТІ ДЛЯ ОРТОТРАНСФОРМУВАННЯ ЦИФРОВИХ АЕРОЗНІМКІВ

Мета. Розробити та виконати дослідну апробацію способу створення карти-маски високих об'єктів місцевості. **Методика.** На основі методу крос-кореляції запропоновано виконувати оцінювання схожості ортофотознімків, які мають взаємне просторове перекриття. Порівняння лівого та правого знімків відбувається попіксельно, для пікселів з одинаковими просторовими координатами *X, Y* і, отже, немає необхідності організовувати пересування пошукового вікна і виконувати пошук відповідних точок як такий. Знімається також обмеження на розмір образу – еталону. Також істотним для вибору саме коефіцієнта кореляції як міри для порівняння зображень є порівняно мала чутливість крос-кореляції до різниць в освітленості сцени. Враховуючи наявні перспективні спотворення зображень високих об'єктів місцевості, очікувано, що кількість пікселів з негативним зіставленням є істотно вищою для ділянок із зображеннями таких об'єктів. Загальна картина на всій території дослідження є картою-маскою високих об'єктів місцевості. Таку карту можна сформувати за допомогою геоінформаційного моделювання полігональних об'єктів, що оконтурюють зони з високою щільністю пікселів із негативним результатом зіставлення. **Результати.** Розглянутий спосіб створення карти-маски високих об'єктів місцевості забезпечує можливість отримати важливу інформацію про якість задання цифрової топографічної моделі поверхні, яку використовують у разі ортотрансформування аерознімків. Виявлений ефект ущільнення точок з негативним результатом взаємного зіставлення ортозображень за методом крос-кореляції дає змогу ідентифікувати і встановити просторове положення високих об'єктів місцевості, таких як дахи будівель, огорожі, лінії електропередач, крони дерев та кущів. **Практична значущість.** Приведено приклад застосування карти-маски високих об'єктів місцевості для проведення ліній зшивання ортозображень.

Ключові слова: аерознімання, ортофототрансформування, ортофотоплан, зшивання ортознімків.

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