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SUPPLY OF PHOTOGRAMMETRIC PROJECTS WITH REFERENCE INFORMATION OBTAINED FROM LARGE-SCALE AERIAL IMAGES

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Objective. Permanent growth of the volume of remote-obtained information about location sets have challenged tasks for scientists and experts concerning quality of its processing in terms of efficiency, completeness, subject, and geometrical accuracy. The important precondition for performance of the tasks is to supply reference information for the images. The information is necessary for performance of a photogrammetric process of geometric correction of the images and for presentation of the images and geo-information products, made on their base, in the determined cartographic projection and coordinates. Analysis of current methods in photogrammetry proves substantial prospects for application of geo-referenced images for the transfer of geodesic information onto new images. In the authors' interpretation, those geo-referenced images are called "reference images", because they are pictures of the objects with an exactly defined geodesic position. One should not associate this notion with a reference point in its classical meaning. The main goal of the work is to develop a method to get control images of the location and transfer of the images onto aerial and satellite images. To reach the set goal the authors of the article developed a method to process an aerial image or a series of aerial images of different scales, which supply an informative source for creation of control images. It is proposed to test the developed method experimentally, supplying a block of archive aerial images with reference information. **Methods and findings of the work**. According to the set goal, the authors of the article made analysis of literary sources that describe innovative ways to supply reference information for aerial and satellite images. The researchers propose to use UAVs, preferably of helicopter type, to get a series of aerial images from different altitudes over the reference point. Depiction of the reference point (control image) at an image of the largest scale is appropriately distinguished by the operator or automatically, according to a pre-determined pattern image. The next step is to make a correlation search of the image of a reference point gradually onto the image of a smaller scale. Thus, there is a transfer of the position of a reference point onto a geo-referenced image. The method enables performing geodesic work on the location after the process of main aerial imagey, choosing the position of reference points according to a configuration of an actual photogrammetric block of aerial images. There is no need of clear contours on a location. **Scientific novelty and practical importance**. The research first gives a concrete explanation of the notion of "control image" for the tasks of geometric correction and geo-referencing of aerial and space images. The work proposes the method to get a control image from an UAV – aerial image or a series of aerial images of different scales. Effect of the method is demonstrated on the example of supplying a block of aerial images of a little-contour location with reference information. Results of approbation of the proposed method secure more efficient geodesic support for photogrammetric projects by means of refusal from physical layout of the location of an aerial image.

Key words: geodesic support for aerial-space images, referencing of large-scale aerial images, layout of a location, GCP (Ground Control Points), CP (Control Points)

Introduction

Geometric correction and geo-referencing of aerial and space images are important parts of the technological process of getting of the images with geometrically accurate, correct geo-data, necessary for implementation of photogrammetric projects. Brining of a portrait depiction of a location to geometric parameters, determined by a set cartographic projection and coordinates, is based on specification of the elements of exterior orientation of the images, and it can be done immediately at the moment of depiction formation (fixing position of a shooting system in geodesic space by appropriate devices) or analytically, with application of reference information (reference points, directions) [Grussenmeyer and Al Khalil, 2002]. In topographic-geodesic production, the traditional approach to support space and aerial images with ground reference and control points is the most often used. On a location, geodesic methods (mainly by means of GNSS receivers) help to determine space coordinates of contour or marked points on the location (in case a geodesic preparation is made before aerial or space image). Simultaneously, a traverse sketch (sometimes – a photo traverse sketch) of the reference point is developed. After office processing, the operator visually distinguishes reference points on the images of a photogrammetric block or on a space image. Such re-identification of the points, on at least one of the images, is almost the only manual operation in the technological process. The very process of points' identification and pointing of the measuring cursor on it inevitably incurs mistakes and errors. Examples of the scientific works, devoted to the results of researches concerning accuracy of identification and pointing of the measuring cursor on the image of reference and control points, both marked and contour points of a location, include the researches by: [Shirokova et al., 2010; Knizhnikov et al., 1999].

Starting from the late 1990s, with introduction of the methods of computer processing of images into photogrammetric technologies, a set of new analytical methods of exterior orientation of aerial space images was developed. Application of such data, as digital images of reference points (physically, before shooting of the marked contours, or chosen on natural or artificial ones), 3D models of separate objects of the location, digital topographic plans and maps, and digital orthophotos in the function of reference information is a particularity of the methods. Some methods of geo-referencing, which use typical sets of geo-data, such as digital topographic maps, orthophotos, and Digital terrain models (DTM), were studied within the OEEPE project «Automatic Orientation of Aerial Images on Database Information» by the European organization for experimental photogrammetric research. Results of the project are presented in the work [Höhle,1998; Läbe and Ellenbeck, 1996; OEEPE Seminar Report, 1999]. The work [Jędryczka, 2000] gives results of determination of the elements of exterior orientation of aerial images according to the sets of vector cartographic information (linear and point objects). A high quality attainment of the problem solution is secured at medium scales of shooting and requires an appropriate reliable and actual database of topographic images. The method, presented in the work [Höhle, 1999], proposes to use an orthophoto as reference information. It is the source for pattern images of reference points of the location for their visual comparison with the points of new aerial images. Implementation of such an approach using an orthophoto requires an available DTM of the adequate accuracy for interpolation of the altitudes of reference points, chosen on the orthophoto. Development of the method by means of substitution of the manual choice of reference and control points at an image with an automatic procedure of correlation search is described in the works [Potůčková, 2004 and 2005]. Paszotta [Paszotta, 1999] proposes to determine the elements of exterior orientation by minimization of the degree of similarity between archive (geo-referenced ones of appropriate accuracy) and new orthophotos (approximately geo-referenced ones). Shan (1999) and Höhle (1998) automatically compared an archive ortho image with new images, and specification of the elements of exterior orientation was made by means of recovery of the set of projecting beams under the determined space coordinates of reliably distinguished points of the orthophoto. The authors propose to make a reverse photogrammetric intersection for exterior orientation of each image separately. It supplies the opportunity to refuse aerial triangulation or simplify their performance [Shan, 1999 and 2001; Paszotta, 1999]. The work [Jaw and Wu, 2004] proposes application of so-called “control patches”. Essentially, they are fragments of archive aerial images with reference points, located in the center of such fragment. Comparison of new aerial images with the archive images is made by an auto-correlator. Approbation of the method grounds its efficiency under conditions of keeping to substantial restrictions, i.e. small changes on the location between the dates of imagey, brining of new and archive images to a common scale, and rather accurately setting of initial parameters of space orientation. A number of successful comparisons of new images, acquired with an interval of 2 years (gsd = 25 cm and gsd = = 7.5 cm) fluctuated from 19 % to 67 %. Elements of exterior orientation of images are iteratively specified. The reached accuracy of determination of linear elements of orientation constitutes 1 m, while corner elements are 1 minute, which is a rather approximate result. Under the condition of a unified scale of images, accuracy of comparison of the corresponding points is estimated by the authors as 0,6–0,8 pixel. There is a well-known method of geo-referencing of aerial space images with application of large-scale horizontal images, obtained from telescopic tripods and bars [Berveglieri and Tommaselli, 2014].

The method expects application of wide-angle cameras of “fish eye” type, which are set on vertical bars and supply taking of the image of a reference point and adjacent location from the position of 4.5 m in height. Geometric resolution of the images is substantially higher than the accuracy of determination of reference points’ coordinates (noting that it is extra information, which does not contribute to the total efficiency of the method), and the very images have substantial geometric distortions. It is a complicated task to eliminate the distortions and it requires a previous laboratory examination of the cameras according to a specific procedure. The next step requires transformation of the images to secure their correspondence to geometric and radiometric parameters of aerial images and stereo identification of the images of reference points with aerial images. The method supplies good results on well-textured contour-rich locations. In the authors' opinion, difference of the conditions in which the images of reference points and aerial images are taken, as well as additional procedures of geometric and radiometric correction of images, make the described method complicated to implement, and the obtained results for poor-contour locations unreliable ones. The work [Nekrasov, 2008] grounds that application of GPS-points for immediate orientation of space images is impossible without loss of their accuracy, because the accuracy of GPS-point identification cannot substantially differ from its spatial resolution. To improve the accuracy of exterior orientation of space images of medium resolution it is proposed to use the methods, according to which, at the first stage, GPS-points are distinguished as of high resolution images (taken, for example, by a KBP-1000 camera with 2 m resolution on the ground, images of Ikonos satellite with 1 meter resolution, and QuickBird with 0,6 meter resolution). At the next stage, the point is transferred onto an overlapping pair of images with medium resolution and exterior orientation is performed. The vivid drawback of this method is that it requires purchase of both high and medium resolution images. However, the former are needed only for geo-referencing and can hardly be used in subject processing of space images. There is still a discussion concerning the issue of comparison of the images, which have different geometry and character of image deformation due to the impact of topography of the location and angle of shooting systems, and difference of radiometric parameters. The author informs that accuracy after exterior orientation of images of high resolution makes 0,5–1,5 pixel, that constitutes 1–3 meter for KBP-1000 images, and 0,5–1,5 pixel – for Ikonos images. Similar conclusions about accuracy of geo-referenced space images are made by the authors of the article [Müller et al., 2010].

The research studies the method of automatic withdrawal of reference and control points from the existing ortho-transformed images with a higher resolution (control images). Efficiency of the method is demonstrated in processing of a large number of space images SPOT 4, SPOT 5, IRS-P6, ALOS. Relative and absolute geometric accuracy of geo-referencing constitutes approximately half of one pixel size. In the later edition of the work, the authors used panchromatic and multispectral images of a very high resolution GeoEye-1 та QuickBird [Müller et al., 2012]. The authors stress that relative, as well as absolute accuracy of geo-referenced space scanned images of high resolution stay within the range of 0.5–1.0 pixel of income image (linear RMSE). Under conditions of anthropogenic landscapes of Europe, a larger part of the stages (95–100 %) can be processed automatically. The available interval of time between taking of pattern and geo-referenced images is from five to seven years. For the regions of ill-defined texture, the method does not supply appropriate results. The authors of the research [Liu and Chen, 2009] propose to use the method of stereo identification of "a point of the image – to the point of geo-referenced image" for the ortho-transformation of Formosat space images.

The same idea makes basis for the approach, which is described in [Ma and all 2017]. Orientation of a space image is made according to another image that was earlier registered in geodesic space. In such case, ground control points are not used. Application of the existing oriented images for performance of a second photogrammetric project improves efficiency of production of geo-spatial products. M. Hamidi and F. Samadzadegan [Hamidi and Samadzadegan, 2015] used referenced images and DTM for orientation of the images from a UAV. However, their method expects application of the images with worse resolution characteristics than the referenced aerial images in the function of control images. Consequently, accuracy of the geo-referencing is not high. The works [Tang et al., 2016] and [Li and all, 2002] also present mathematic models for photogrammetric processing of stereo images, taken by the systems of satellite images of high resolution. Mathematical modeling makes base for analysis of the impact of the number of control points, their spatial distribution, and errors of measuring of the images concerning accuracy of a photogrammetric model of the location. The work concludes that accuracy of determination of ground coordinates under a complete support with control points from 2 to 3 m can be reached by means of space images with a resolution of 1 m and from 5 to 12 m without control points. Automatic method of exterior orientation of images is grounded on application of 3D digital models of spatial objects as reference information and on the basis of comparison of contour structure [Blokhinov and Gorbachev, 2011]. The authors describes the rules to determine local particularities of one-dimensional presentation of contours. Measuring procedures are invariant to mutual turn of aerial images.

In summary, the authors note that all described methods do not exclude distinguishing and manual measuring of the points on images carried out by an operator. Accuracy of determination of orientation elements mainly depends on the quality of the initial cartographic material. However, it not always can be associated with a new performed shooting neither by geometric accuracy (application of instrumentally measured points, lines, and sites on a location by means of geodesic methods) nor by spectral portrait (in case of application of archive orthophotoplans and orthophotos). It is necessary to perform the procedure of radiometric improvement of the images (transfer of a color image into a grey one, change of its contrast and brightness) and their geometric correction (brining to the defined resolution, orientation in space). All the procedures are complicated and do not always supply the expected result. The defined circumstances of preparation of the initial information and referenced images are specific for different shooting systems. Images of the objects on topographic plans and images are not always geometrically similar to their images on referenced images that is well observed at large scale image. The described methods supply more reliable results within the range of medium scale images (smaller than 1:10,000). Large-scale images have substantial peculiarities and restrictions in application of the mentioned methods. Thus, the authors of the article consider that there is an urgent need to correct the described methods of application of reference information because of wide-spreading of new means of ground surface image for all types of shooting systems carriers ranging from space satellites to UAVs.

Cartographic models (including DTM) used as reference information, are mainly the generalized versions of a real terrain image. Thus, there is a great future for the methods which apply control images. The authors stress again that the images are pictures of the objects with known geo-referencing under the condition that such data are correctly obtained and have appropriate radiometric and geometric characteristics.

Objective

The main objective of the work is to develop a method to get control images and transfer the images onto aerial or space images of the location. To reach the set goal, it is necessary to perform:

❖ development of the notion of a “control image” as an instrument to transfer geodesic information onto images or onto a photogrammetric block of images;

❖ development of the method to get an aerial images or a series of aerial images of different scales, which make base for creation of a control image;

❖ experimental testing of the effect of the developed method concerning supply of the block of archive aerial images with reference information.

Methods and results of the work

Considering the fact that the notion of a “control image” is not yet a common one in photogrammetry, the authors of the work give its definition in the article. ***A control image is an image of a location object, created by means of a common mathematic model. Space location of the object is determined in geodesic space with the accuracy, sufficient for performance of the procedures of photogrammetric processing of the images***. A control image is a means to transfer geodesic information onto an image or a photogrammetric block of images. It is clear that depicting properties of a control image should be sufficient for a precise identification of the location object, which has a defined geodesic certificate.

Basing on the above-presented information, the research outlines the condition, required for getting and application of control images in a photogrammetric process.

1) Image of a reference object should be created with preservation of geometric similarity to its image at referenced aerial or space images.

2) Different scales of images (reference and referenced ones) and their mutual space orientation should be determined considering the conditions of organization of the process of visual or automatic stereo identification. Practically, the important parameter is presented by a coefficient of relation of a topographic excess of a stage to the altitude of the image over the stage. The parameter influences the possibility of a correct application of an affine model of the camera in spite of a more general projecting transformation.

3) Size of the control image should be sufficient for a reliable stereo identification. Since their number for a photogrammetric block is small, consumption of time for comparison of the images are not of special practical importance.

4) A reference point at a low-contour location can be determined not necessarily on the contour, and its description and method of choice can consider quality of topologic features of the location, i.e. “in a cross section, on an imaginary crossing, on a prolongation of a line to the imaginary crossing, equally-spaced”.

5) Basing of the common concept of control images application, in practice, it is capable to develop a set of different-scale control images of one object on a location. The process of transfer

of reference information will be performed gradually from a control image with the largest scale of depiction to control images of smaller scale and, finally, to the images of a photogrammetric block.

Thus, generally, a control image is a fragment of images, created around a pixel, which contains depiction of a reference point. Image of a reference point can be easily developed for marks, i.e. pre-developed distinguishing signs, which are physically placed on a location before shooting [Dorozhynskyy and Tukaj, 2009]. However, application of marks encounters some expenses and complexities in their production, placing on a location (assembling before shooting and dismantlement after shooting), and transportation. Image of a contour reference point of a location can be created by application of any cheaper method of aerial image, i.e. to get the image from a small UAV of a helicopter type. Nevertheless, one should note that choice of a location point as a candidate to be applied as a reference or control point in photogrammetric process can be formalized (mathematical argumentation), basing not only on personal experience of a performer of geodesic preparation of a location, but by applying calculations of the autocorrelation function for estimation of the image of any point on a location. An example of application of the correlation function for estimation of a point at images (and the around created image) as a candidate for correlation search is presented in the work. [Potůčková. MATLAB…]. Uniqueness of the control image and its optimal size for a correlation search are defined by estimating of correlation surface. A standard deviation of the values of grey σ_T and entropy H_T supplies estimation of the contrast and amount of radiometric information in the image.

A prototype of the proposed method is known for analogue images, when an operator transferred a position of control points from an image to an image manually [Shkurchenko, 2004; Boshnyakovich and Glebovskiy, 1963]. The method, described in the article, opens a new way to a more efficient geodesic support, particularly for a low-contour territory. Moreover, the proposed approach does not require placing of the points immediately on the contour of a location, i.e. on the boundary, which separates objects with different brightness. We use the fact that such differences of brightness are always present in some surrounding of a landscape around the point. The fragment of a landscape forms a unique image of each point of the location.

The proposed principle of geodesic support for a photogrammetric block of aerial images is illustrated by the Fig. 1.

The procedure of gradual comparison (or identification) of two images (in the present case – the image of a control point $g(x, y)$ with a set of images $f_i(x,y)$ of aerial or space images is well-developed in digital photogrammetry and secures a high (subpixel) geometric accuracy. To prove the fact, the authors give examples of application of control images to supply control points for a photogrammetric block of aerial images from a UAV.

Example 1. There is a topographic aerial image of rural area, made by a UAV of plane type. Resolution of the images is gsd = 0,075 m/pix, the average altitude of shooting over the location is H = 200 m. A part of the location in the middle of the block of aerial images has insufficient texture parameters for automatic distinguishing of a sufficient number of linking points between the images. The location is expectedly the weakest one in the photogrammetric net.

After the main aerial image on the location, the authors marked a reference point with a carton rectangle (4x6 cm), which contrasted to the color of the underlying surface. Space coordinates of the point are measured with a GPS receiver of geodesic class in RTK-regime. Over the reference point, the researchers produced a series of three different-scale aerial images, i.e. at altitudes of 50, 100, 150 m respectively, by means of a UAV of a helicopter type (Fig. 2).

On the images of the largest scale, the operator identified a new reference point. On the other images, its position was determined by autocorrelator in Pix4D program. Thus, the existing block of aerial images is supplemented with new reference information, which substantially improves the accuracy of photogrammetric processes performance. The new supplementary aerial images can serve only in obtaining a control image or can be included into a block of aerial images.

Example 2. Condition of aerial images were identical to the ones described in the example 1. There was a swamp meadow in the central part of the surveyed location andthe territory was of low contrast. The principal aerial image was taken at the altitude of 200 m. The only supplementary aerial images, which included a control image, was taken at the altitude of 75 m (Fig. 3).

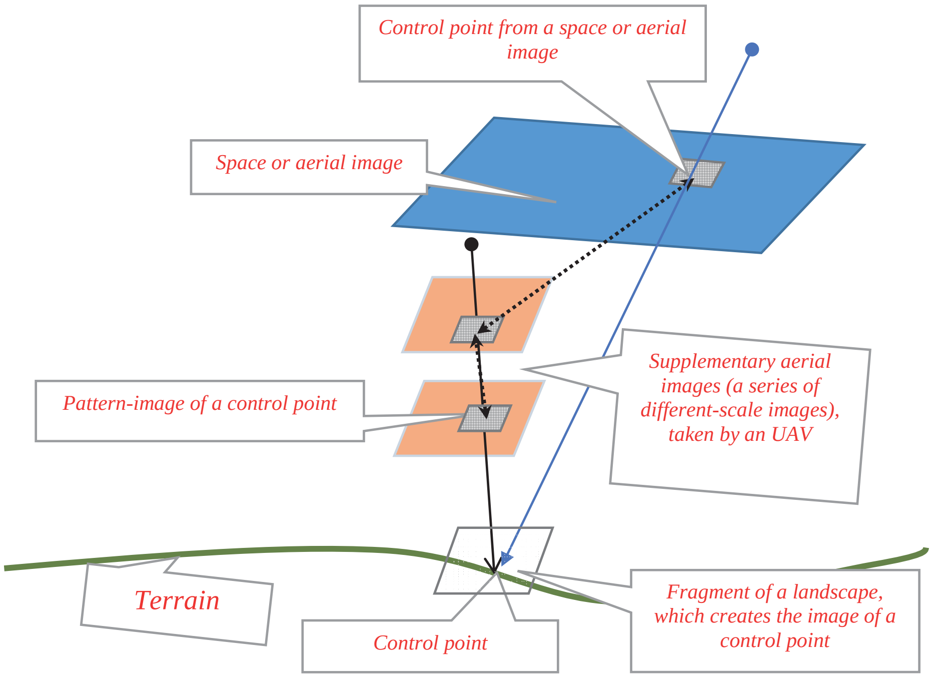

Fig. 1. Scheme of the proposed method to compose control images

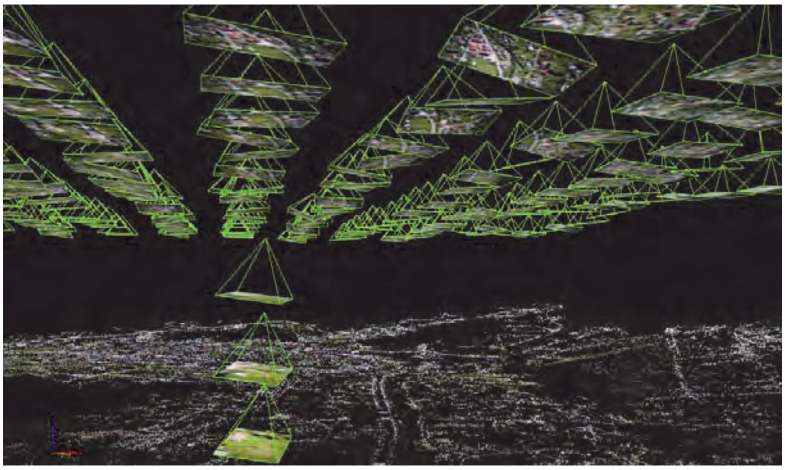

Fig. 2. Principle of supplementing a block of aerial images with new images, presenting the image of a reference point

Fig. 3. Aerial photos of the low textured area. Left: H = 75 m; Right: H = 200 m

In the example, scales of the images of the reference point at principal and supplementary images differ 2.7 times. The reference point was not marked on the terrain. The point was chosen at a rather low-observable micro-contour, which was well visible only in the supplementary images. Photogrammetric measuring and transfer of the reference point's image onto aerial images were performed by means of autocorrelator of Fotomod software. Results of a successful identification at a threshold value of 0,92 correlation coefficient are demonstrated by the Fig. 4.

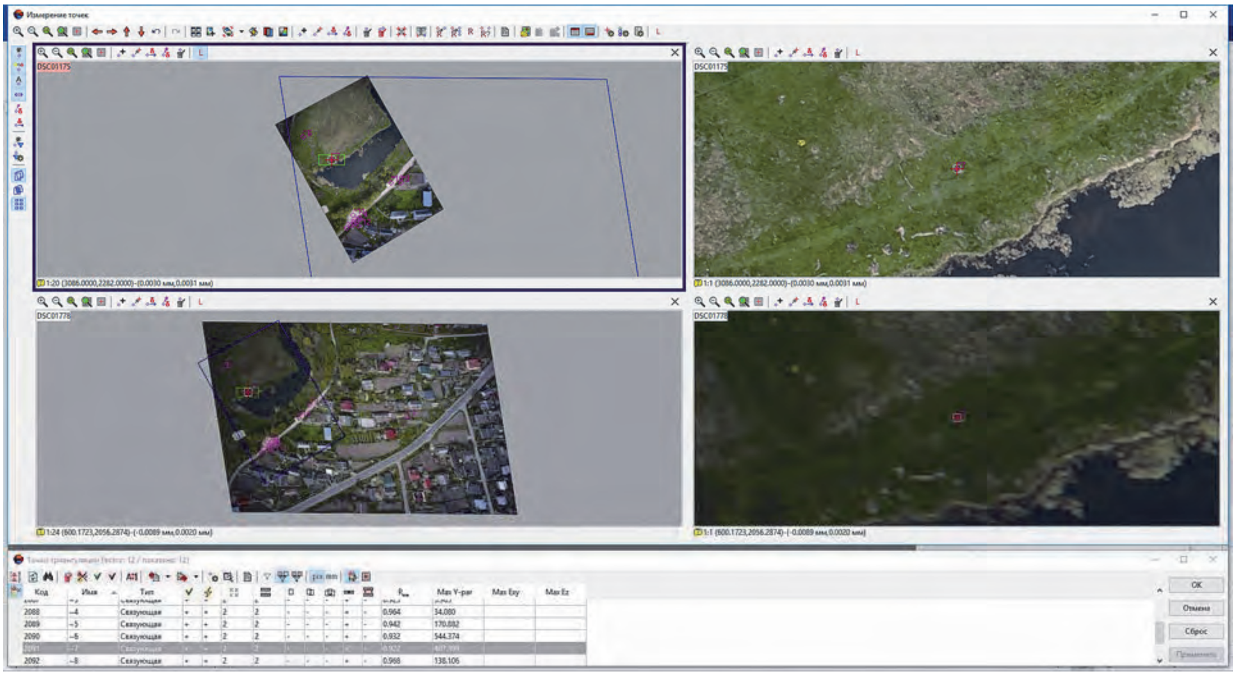

Fig. 4. Result of the transfer of the image of a reference point by an autocorrelator from a control image onto an aerial image

The carried experiments demonstrate efficiency of the proposed technology. Application of additional equipment in the form of an UAV is not the principal problem of economic and organizational character for the proposed method. An UAV of semipro type ("Fanthom-3") costs 1,000 USD. Considering a multiple use of the UAV, expenses for its purchase and employment are commensurable with the costs of production, shipping, and placing of the marks on a location in the projects, which are made by a small enterprise during a year. Flying of light drones does not require specific professional skills. In Ukraine the administrative permissions for light copters are not needed even for flights within settlements (a restriction is in cities and of military objects).

Scientific novelty and practical importance

The research first gives a definition of the notion of a "control image" for the tasks of geometric correction and geo-referencing of aerial and space images. The work proposes the method to get aerial images and a series of different-scale aerial images by means of an UAV and the images are the source for the creation of a control image. Success of the method is demonstrated with the example of the supply of reference information for the blocks of aerial shooting of low-contour locations. Results of approbation of the proposed method argue the possibilities of more efficient performance of geodesic support for photogrammetric projects by means of refusal from physical layout of a location before an aerial image.

Conclusions

Flexibility of the proposed technology is revealed in a greater number of variants concerning the choice of reference information and performance of additional images in case of the necessity to improve conditions of photogrammetric procedures. An operator distinguishes a point only once. It can be done immediately during the field performance of geodesic support for a block of aerial images or by referencing space images. During office processing, in most cases it is possible to avoid pointing of the cursor and the related divergences, faults, and errors. The mentioned method can also be applied to low-contour locations in case of a great number of pattern-images. Thus, in many cases, physical layout of points is useless. That is the way to a more efficient photogrammetric technology.

A prospect of future research is to determine the methods of transfer of reference information onto various aerial and space images and define accuracy parameters of different methods.

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ЗАБЕЗПЕЧЕННЯ ФОТОГРАММЕТРИЧНИХ ПРОЕКТІВ ОПОРНОЮ ІНФОРМАЦІЄЮ, ОТРИМАНОЮ З ВЕЛИКОМАСШТАБНИХ АЕРОЗНІМКІВ

Мета. Постійне зростання об'ємів дистанційно отримуваної інформації про місцевість ставить перед науковцями та практиками складні завдання щодо якісного її опрацювання у сенсі оперативності, повноти, тематичної та геометричної точності. Важливою передумовою виконання цих завдань є забезпечення знімків опорною інформацією. Вона необхідна для виконання фотограмметричного процесу геометричної корекції зображень та представлення цих зображень і створених на їх основі геоінформаційних продуктів у визначеній картографічній проекції та системі координат. Аналіз наявних у сучасній фотограмметрії методів вказує на значні перспективи застосування геоприв'язаних зображень для перенесення геодезичної інформації на нові знімки. У нашому трактуванні ці геоприв'язані зображення називають **"опорні образи",** бо це зображення об'єктів, геодезичне положення яких чітко визначене. Не слід ототожнювати це поняття з опорною точкою з її класичним визначенням. Основною метою роботи є розроблення способу отримання опорних образів і перенесення цих образів на аеро- або космічні знімки місцевості. Для досягнення поставленої мети ми розробили спосіб опрацювання аерознімка чи серії різномасштабних аерознімків, який/які є інформаційним джерелом для створення опорних образів. Перевірити дію розробленого способу для забезпечення блока архівних аерофотознімків опорною інформацією пропонується експериментально. **Методика та результати роботи**. Відповідно до поставленої мети виконано аналіз літературних джерел, які описують новітні способи забезпечення опорною інформацією аеро- та космічних знімків. Ми пропонуємо використовувати БПЛА, найкраще вертолітного типу, для отримання серії аерознімків з різних висот над опорною точкою. Зображення опорної точки (опорний образ) на знімку найбільшого масштабу надійно розпізнаються оператором або автоматично за її наперед сформованим еталонним зображенням. Далі виконується кореляційний пошук образу опорної точки послідовно на зображення меншого масштабу. Таким чином відбувається перенесення положення опорної точки на знімок, що підлягає геоприв'язці. Спосіб дає можливість виконувати геодезичні роботи на місцевості після процесу основного аерознімання, вибираючи положення опорних точок відповідно до конфігурації реального фотограмметричного блока аерознімків. Не обов'язковим є наявність чітких контурів на місцевості. **Наукова новизна та практична значущість.** Вперше конкретизовано зміст поняття "опорний образ" для задач геометричної корекції та геоприв'язування аеро- та космічних знімків. Запропоновано спосіб отримання опорного образу з БПЛА-аерознімка або серії різномасштабних аерознімків. Дію способу продемонстровано на прикладі забезпечення опорною інформацією блоків аерознімків малоконтурної місцевості. Результати апробації запропонованого способу дають змогу ефективніше виконувати геодезичне забезпечення фотограмметричних проектів за рахунок відмови від фізичного маркування місцевості перед аерозніманням.

Ключові слова: геодезичне забезпечення аерокосмічних знімань, прив'язка великомасштабних аерознімків, маркування місцевості, GCP (Ground Control Points) – наземні точки прив'язки; CP (Control Points) – контрольні точки.

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