# CARTOGRAPHY AND AERIAL PHOTOGRAPHY

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## METHOD OF CONTROL POINTS COLLECTION FOR GEOREFERENCING AERIAL IMAGES

**Aim.** Determination of the elements of external spatial orientation of the surveying systems at the moment of image acquisition is the fundamental task in photogrammetry. Principally, this problem is solved in two ways. The first way is direct positioning and measuring directions of the camera optical axis in the geodetic space with the help of GNSS/INS equipment. The second way is the analytical solution of the problem using a set of reference information (often such information is a set of ground control points whose geodetic positions are known with sufficient accuracy and which are reliably recognised on aerial images of the photogrammetric block). The authors consider the task of providing reference and control information using the second approach. This approach has a number of advantages in terms of reliability and accuracy of determining the unknown image exterior orientation parameters. It is proposed to obtain additional images of ground control points by the method of their auxiliary aerial photography using an unmanned aerial vehicle (UAV) on a larger scale compared to the scale of the images of the photogrammetric block. The aim of the presented work is the implementation of the method of creating reference points and experimental confirmation of its effectiveness for photogrammetric processing. **Methods and results**. For the entire realization of the potential of the analytical way to determine the elements of external orientation of images, it is necessary to have a certain number of ground control points (GCP) and to keep the defined scheme of their location on the photogrammetric block. Authors use UAV aerial images of the terrain as the main source of input data. They are obtained separately from the block of aerial survey, have a better geometric resolution and clearly depict the control reference points. Application of such auxiliary images gives the possibility of automated transferring the position of ground control point into images of the main photogrammetric block. In our interpretation, these images of ground control points and their surroundings on the ground are called "control reference images". The basis of the work is to develop a method for obtaining the auxiliary control reference images and transferring the position of GCP depicted on them into aerial or space images of terrain by means of computer stereo matching. To achieve this goal, we have developed a processing method to create control reference images of aerial images or a series of auxiliary multi-scale aerial images obtained by a drone from different heights above the reference point. The operator identifies and measures the GCP once on the auxiliary aerial image of the highest resolution. Then there is an automatic stereo matching of the control reference image in the whole series of auxiliary images in succession with a decrease in the resolution, and, ultimately, directly with the aerial images of the photogrammetric block. At this stage, there is no recognition/cursor targeting by the human operator, and therefore there are no discrepancies, errors or mistakes related to it. In addition, if you apply a fairly large size of control reference images, the proposed method can be used on the low-texture terrain. Therefore in many cases it is possible to do without the physical marking of points measured by the GNSS method. And this is a way to simplify and reduce the cost of photogrammetric technology. The action of the developed method has been verified experimentally to provide the control reference information of the block of archival aerial images of the low-texture terrain. The results of the experimental approbation of the proposed method give grounds to assert that the method allows performing geodetic reference of photogrammetric projects more efficiently due to the refusal to mark the area physically before the aerial survey. The proposed method can also be used to obtain the information for checking the quality of photogrammetric survey to provide check points. The authors argue that it is economically feasible to use such additional equipment,as UAV of semi-professional class, to obtain control reference images. **Scientific novelty and practical relevance.** For the first time, the study presented the results of approbation of the “control reference image” method with obtaining stereo pairs of aerial images with vertical placement of the base. It also examined the properties of such stereo pairs of aerial images to obtain images of reference points. The paper showed the effectiveness of including reference images in the main block of the digital aerial triangulation network created on UAV’s images.

*Key words:* geodetic referencing aerospace surveys, referencing large-scale aerial images, matching, GCP (ground control points); CP (check points).

## Introduction

The development of digital photogrammetric technologies demonstrates the expansion of methods of obtaining and applying reference information. It is necessary for fixing images in the geodetic space and, ultimately, for the results of their photogrammetric processing. In addition to GCP, other elements are used as reference information. First of all, we are talking about the centers of projections, the spatial coordinates of which are determined by satellite methods during the aerial survey and the navigation angles of the images, which are measured by inertial navigation systems [Kolb, 2000]. Linear and angular measurements in the area, depicted in aerial images, have become much less widespread as reference information. Techniques for handling such information are well known in analytical photogrammetry and at the present stage are implemented in the processing of blocks of digital aerial images obtained from UAVs [Gerke, & Przybilla, 2016; Stöcker, et al., 2019; Wiącek, & Pyka, 2019]. We should separately acknowledge the study of hardware and software implementations of such surveys with different configurations of reference data [Przybilla, et al., 2019; Peppa, et al., 2019; Kotov, 2018].

Advances in computer image processing allowed for the active development of the methods of images application that have a geodetic reference or include spatial objects with known coordinates as reference information. Especially, it refers to such two relatively new areas, as the large-scale aerial survey from UAV and space imaging of ultra-high spatial resolution. Most of these methods suggest using archival orthophotos, aerial triangulation data from previously performed images and digital plans and maps as reference images [Fedotkin, 2000; Method of identification of control points…, 2019]. There are very few developments of this kind for aerial photography from UAV. Among the recent work, we can note the paper [Hamidi, & Samadzadegan, 2015], in which the authors consider a previously created 3D model of the area as a variant of the reference information.

In the article [Kolb, 2018], we performed an overview of current research in this area. Our research focuses on a ground control point as the basic carrier of reference information. And the reference image is considered only as a dataset necessary for the application of automatic (or automated) methods of reliable recognition of a point in other images. This approach can be rationalized by the following fact [Kolb, 2000; Stöcker, & all, 2019].When performing aerial triangulation, the optimal number and quality of ground control points largely compensates for a number of the shortcomings of surveying parameters. Such shortcomings include suboptimal image overlap (especially inter-route overlap), lack or inability to use frame routes and other conditions. Finally, the ability to adjust data by supplementing existing photogrammetric images with new reference information is a significant advantage in obtaining the main purpose of photogrammetric processing. As follows from [Wim van Wegen], the purpose is to create an accurate model of the object or area.

## Aim

In [Kolb, 2018], we formulated the idea of the reference image as a carrier of video information intended for the recognition of the GCP in the automated photogrammetric system. Its essence is obtaining aerial images or a series of aerial images of different scales by additional aerial photography from a quadcopter directly above the GCP on the terrain. As a reference image, we consider the image of a terrain point formed according to a well-known mathematical model, the spatial position of which in geodetic space is set with an accuracy sufficient to perform photogrammetric image processing [Kolb, 2018]. The images obtained in such a way are used for reliable and geometrically accurate recognition of the GCP in aerial images of the largest scale. They are also used for the automatic transfering of this information to the images of the main block of aerial photography or to a space image. The purpose of this article is to verify the fundamental possibility and analyze the effectiveness of the use of images of ground control points obtained from the UAV surveys as reference images of the area. The geodetic coordinates of GCP are known (for example, determined by GNSS survey methods).

## Methods and results

Photogrammetric methods of aerial triangulation development, creation of orthophotos, digital object models and other products involve the creation of a dense or sparse network of ground control points (GCP) and check points (CP).

Most existing technologies for creating networks of ground control points and checkpoints include field work on marking these points on the ground and conducting geodetic works in order to obtain their spatial geodetic coordinates. Quite often, clear terrain structures recognized in aerial images are chosen as ground control points [Dorozhynskyy, 2002].

These technologies have certain disadvantages, which include:

- ambiguity of point recognition in aerial images;
- the complexity of automating photogrammetric measurements of GCP/CP in many images; the errors of the first recognition will be repeated during the computer matching operations;
- it is almost impossible in practice to transfer the position of the ground control point to the photogrammetric project without losing the accuracy of their geodetic coordinates.

To eliminate these shortcomings, we proposed to conduct additional UAV surveying and obtain images whose scale is larger than the scale of the main (aero or space survey). UAV surveying takes place directly above the reference point to obtain a series of aerial images from different heights, i.e. with a vertical base of surveying.

Let us consider the case when it is necessary to transfer the position of the GCP depicted in the images of UAV-surveying to aerial images which were obtained before its marking. In this case, the GCP point is virtual and cannot be visually identified in aerial images. To determine the position of such a virtual GCP point in aerial image we propose an approach based on the well-known photogrammetry properties of central projection and on the application of methods for matching special points in images.

The image of the ground control point (we will call it the reference image obtained after marking the point on the ground and determining its spatial geodetic coordinates) will be placed in the image plane in a position close to zone with minimum deformation under the conditions of obtaining the image [Dorozhinskyy, 2015, p. 21]. The property of this point is that the angles with the vertex in it in the image of the central projection are not deformed and nearly correspond to the actual angles on the ground and on the orthophoto.

The methods of computer comparison (matching) of the corresponding points (Fig. 1) determined the special points (according to the brightness features) in the reference image and in the aerial image, on which the position of the virtual ground control point is supposed to be defined, In terms of photogrammetry, these points are related to both images, and their number is different for different types of landscapes and computer matching techniques. The ground control point in the general case is not special in this sense and cannot be automatically matched. Its position can be obtained by calculation.

One of the ways to solve the problem is to apply the solution of the inverse angular intersection known in geodesy. This way is suitable when the image, which has to be referenced, is tilted.

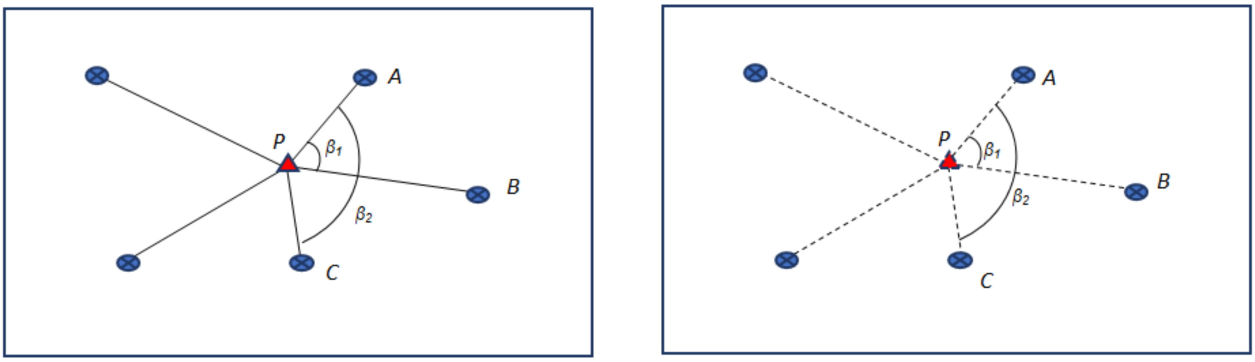


*Fig. 1. Position of ground control point and special points on reference image (left) and aerial image which has to be referenced (right)*

Suppose we have three tie points A, B, C whose coordinates on the image, which has to be referenced respectively are: (($X_A$, $Y_A$), ($X_B$, $Y_B$), ($X_C$, $Y_C$)). Let's denote the ground control point by the letter P; one of the tie points, the direction of which from the point P is close to the abscissa (X) by the letter B; the tie point to the left of point B (if viewed from point P) by the letter A; the third tie point by the letter C; the central angles from the point P to the tie points the letterβ. The order of calculations is as follows [Selikhanovych, 1981, p. 398]:

– calculate the directional angle $a_{PA}$ of the side *PA* according to the formula:

$$\tan\alpha_{PA}=\frac{(Y_B-Y_A)\mathrm{ctg}\beta_1+(Y_A-Y_C)\mathrm{ctg}\beta_2+(X_C-X_B)}{(X_B-X_A)\mathrm{ctg}\beta_1+(X_A-X_C)\mathrm{ctg}\beta_2-(Y_C-Y_B)} \quad (1)$$

– calculate the directional angles $a_{PB}$ of the side *PB* and $a_{PC}$ of the side *PC* according to the formula:

$$\alpha_{PB}=\alpha_{PA}+\beta_1; \qquad \alpha_{PC}=\alpha_{PA}+\beta_2; \quad (2)$$

– calculate the coordinates of virtual GCP *P* on the image, which has to be referenced:

$$X_P-X_C=\frac{(X_A-X_C)\tan\alpha_1-(Y_A-Y_C)}{\tan\alpha_1-\tan\alpha_3};$$

$$Y_P-Y_C=(X_P-X_C)\tan\alpha_3 ... \quad (3)$$

In the general case, the referenced aerial image is oblique (i.e. there are perspective deformations, and therefore deformed directions) and the virtual reference point in such an image is not at the focal point. In this case, the use of inverse angular intersection is not justified.

Considering that the image deformations in the referenced aerial image is nonlinear, it is advisable to use a system of equations of third-order polynomials for transformation using *n* tie points with coordinates (*x, y*). One tie point allows you to make two equations of the form:

$$\left.\begin{aligned} x_t &= a_0+a_1x-a_2y+a_3x^2+a_4xy+a_5y^2+a_6x^3+a_7x^2y-a_8xy^2+a_9y^3 \\ y_t &= b_0+b_1x-b_2y+b_3x^2+b_4xy+b_5y^2+b_6x^3+b_7x^2y-b_8xy^2+b_9y^3 \end{aligned}\right\} \quad (4)$$

For *n* tie points (*n>9)* we will make a system of equations, from the solution of which we can determine the coefficients of the polynomial *a, b*. Then, by equation (4) we will find the coordinates of the virtual ground control point on the referenced aerial image. In the case of using a larger number of tie points, we apply the method of least squares, i.e. the solution is obtained from a system of normal equations.

There are many important caveats when using terrain points as ground control points. In particular, this relates to areas with high buildings. In the work [Kolb, 2019], we propose a posteriori assessment of the quality of the ground control network by creating a map of high objects off terrain. The method of creating such a map involves the correlation of two orthotransformed images without using a sliding window. According to our research, the number of points with a negative correlation of two orthotransformed images is significantly higher for images of areas with high terrain objects. The general picture of the density of points with a negative comparison result throughout the study is presented in the form of a map of high terrain objects. Such a map can be formed as a set of polygonal objects that outline areas with a high density of obtained points with a negative correlation. It gives the possibility to estimate the location ground control and check points relative to these polygonal objects (Fig. 2).

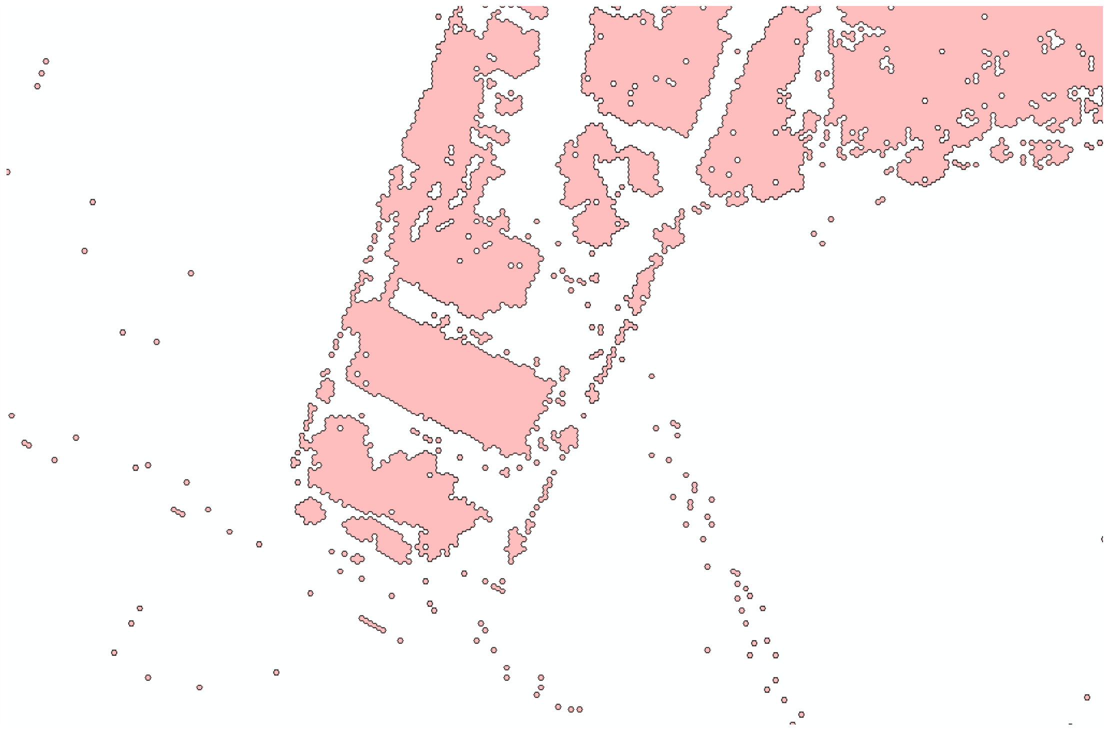

*Fig. 2. Example of automatic selection of area on the map, where the location of ground control and check points is undesirable*

To provide the recognition of the ground control point with the highest accuracy, we plan to use a drone to obtain one or more images above the ground control or check point from different heights. The number of these images and their spatial resolution is determined from the possibility of reliable software identification of the corresponding points. The invariant (non-sensitive to large-scale distortion) point descriptors are used for the most common method of identifying the corresponding image points of stereo pairs in photogrammetric software Semi Global Mathcing . The recognition of the ground control point in the image of the highest resolution is performed by the operator. And then the automatic alternate software identification of the corresponding points of different-scale images with subpixel accuracy is performed.

As an example of practical implementation of the described approach, we present the results of processing two series of three aerial images each, obtained from heights of 50 m, 100 m, and 150 m above the points of the terrain, where the spatial coordinates were determined by GPS method. Manual identification was performed by the operator only on images obtained from a height of 50 m. The Pix4D software was used for experiment matching (Fig. 3).

We conducted research on the formation of a dense cloud of points for low-texture terrain. To solve this problem, we used stereo pairs composed of aerial images of different scales. This feature can be interesting when we need to densify existing point clouds to reproduce more detailed terrain and object models. Of course, we should take into account the fact that the density of the point cloud required for high-quality 3D modeling differs significantly for different objects. To study the effectiveness of this approach experimentally, we obtained the block of aerial images by UAV from a height of 200 m. In this block, we included an additional aerial photograph obtained from a height of 75 m for more reliable modeling of a part of the area with low texture – meadow in the river floodplain. Software PhotoModeler Premium (*https://www.photomodeler.com/products/premium/*) was used (Fig. 4).

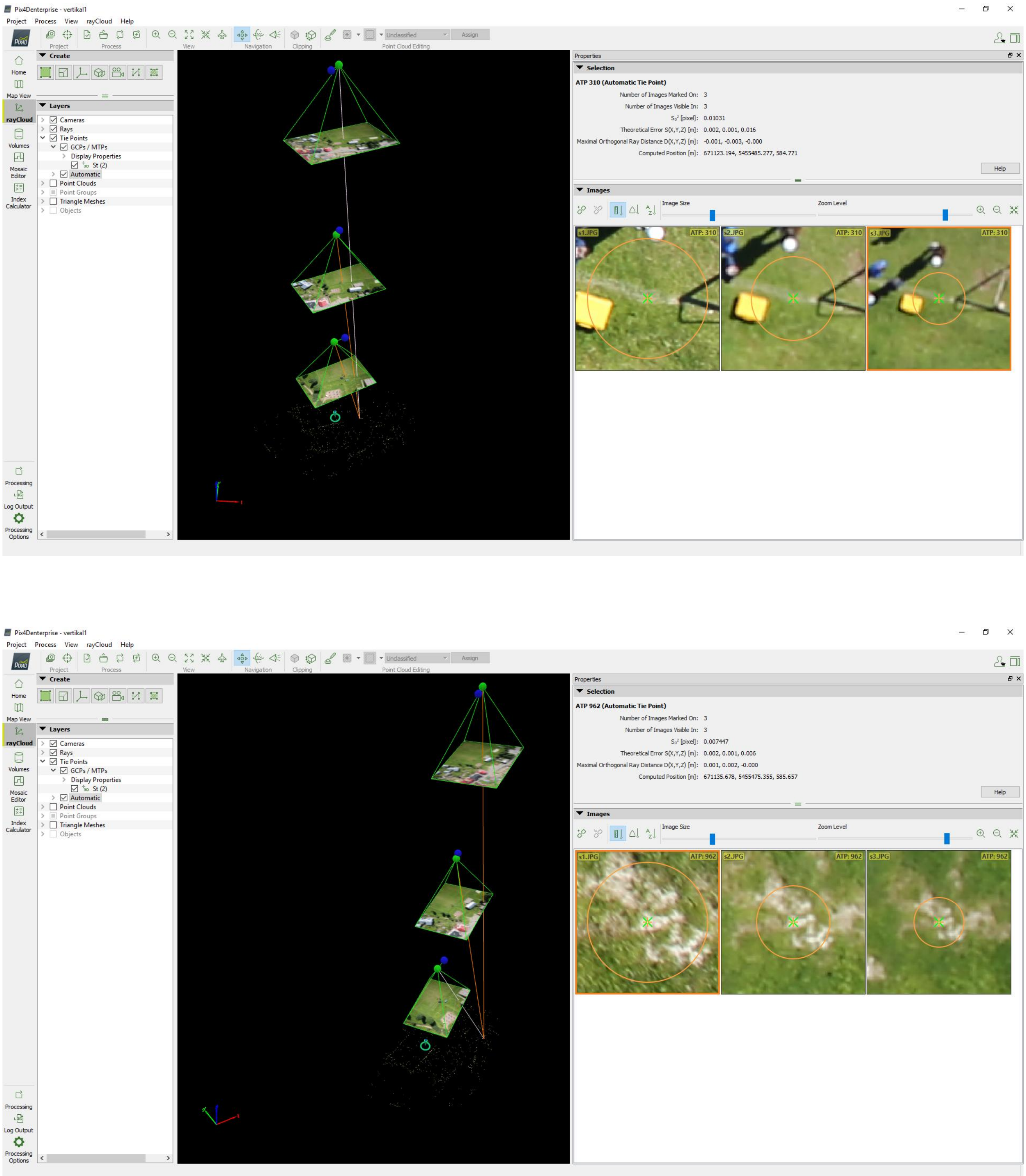

*Fig. 3. Examples of implementation of automatic identification of points on different-scale aerial photographs*

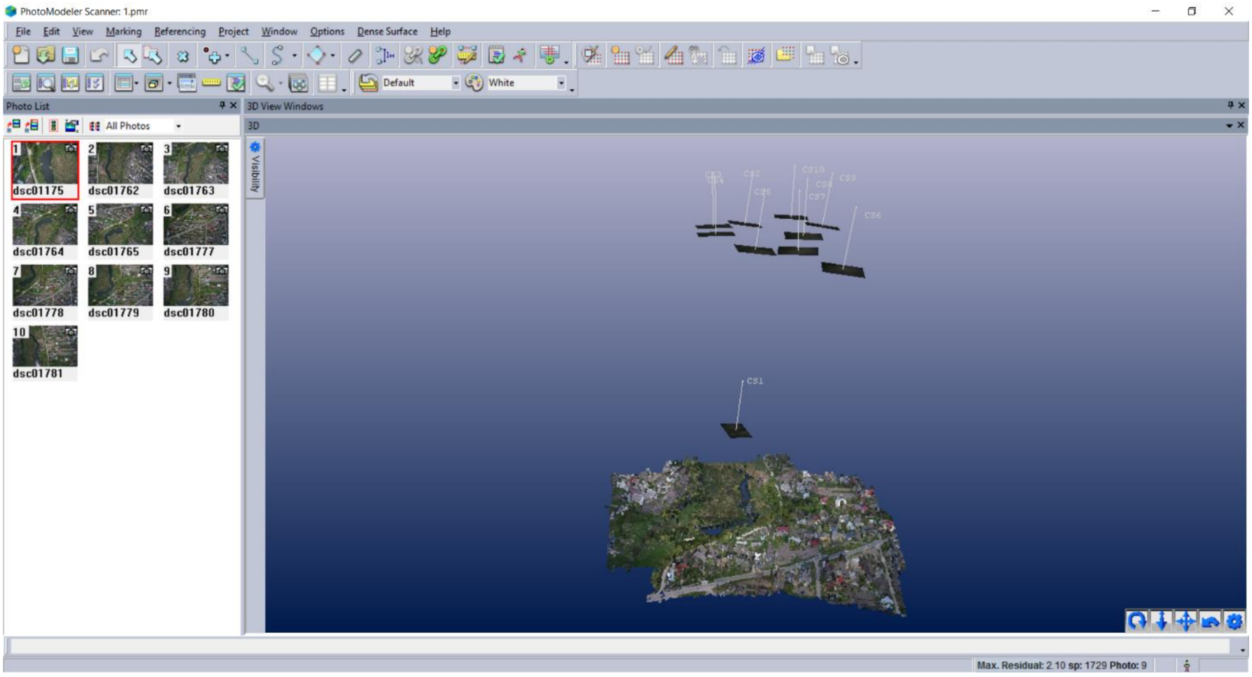


*Fig. 4. Example of including an additional aerial image in larger scale in an existing block of basic aerial images*

As seen in the figure, the method of dense stereo reconstruction SFM, which in our case is implemented in the software PhotoModeler Premium, fully accomplishes the task. The additional aerial image was successfully included in the network of basic scale images and was also used in the process of dense computer stereo reconstruction.

## Scientific novelty and practical relevance

The results of approbation of the "control reference image" method with obtaining stereo pairs of aerial images with vertical placement of the base are presented for the first time. We studied the properties of such stereo pairs of aerial images to obtain images of reference points. The research proved the effectiveness of including reference images in the main block of the digital aerial triangulation network created on UAV's images.

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## Conclusions

High accuracy of implementation of photogrammetric projects for various purposes (topographic, engineering, etc.) can be ensured by using high-quality networks of ground control and check points. The analysis of the factors that influenced the accuracy of photogrammetric constructions is performed in the work and the following recommendations are formulated:

1. The application of the method of creating and using a "virtual reference point" allows automatic performing its high-quality recognition and inclusion in the photogrammetric block for further high-precision processing.
2. The use of correlation in two adjacent aerial images allows you to identify areas with high objects, where the choice of reference images is difficult or undesirable.
3. For reference provision of low-texture areas (e.g. meadow), we suggest using drones to obtain additional images of different scales, and then move the position of the GCP from a large scale to a smaller one, applying semi-automatic procedure. This action is carried out without complications and additional settings by modern photogrammetric software packages. This method

can be helpful to avoid marking points procedure before aerial survey and will be useful if there is a need for additional GCP after implementation of survey when the marking is impossible.

The prospect of future research is elaboration of the methods of transmission of reference ground control information into different aerospace images and determination of accuracy parameters of different methods.

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# МЕТОД ОТРИМАННЯ ОПОРНИХ ТОЧОК ДЛЯ ГЕОМЕТРИЧНОЇ КОРЕКЦІЇ АЕРО ТА КОСМІЧНИХ ЗНІМКІВ МІСЦЕВОСТІ

**Мета**. В фотограмметрії фундаментальною задачею є визначення елементів зовнішного просторового орієнтування знімальних систем на момент отримання ними зображень. Принципово ця задача вирішується двома шляхами. Перший шлях – пряме позиціонування та вимірюванням напрямків орієнтування оптичної осі камер в геодезичному просторі з допомогою GPS/INS апаратури. Другий шлях – аналітичне вирішення задачі з допомогою набору опорної інформації (найчастіше такою інформацією є набір опорних точок, геодезичне положення яких відоме з достатньою точністю і які надійно зчитуються на аерознімках фотограмметричного блоку). Автори розглядають завдання забезпечення опорною і контрольною інформацією саме другого підходу, який має ряд переваг щодо надійності та точності визначення шуканих параметрів орієнтування знімків. Отримувати зображення опорних точок пропонується за методом додаткового їх аерознімання з допомогою БПЛА в більшому масштабі порівняно із масштабом знімків фотограмметричного блоку. Метою представленої роботи є реалізація методу створення опорних точок та експериментальне підтвердження його ефективності для фотограмметричних опрацювань. **Методика та результати роботи**. Для повної реалізації потенціалу аналітичного шляху визначення елементів зовнішнього орієнтування знімків необхідна наявність певної кількості опорних точок та дотримання визначеної схеми їхнього розміщення в охопленні фотограмметричного блоку знімків чи космічного знімка. Як джерело опорної інформації автори виокремлюють аерознімки місцевості, які отримані автономно від основного знімання (наприклад, з квадрокоптера), мають краще геометричне розрізнення і на яких зображено опорні точки. З таких допоміжних знімків є можливість автоматизованого перенесення зображень опорних точок на знімки основного фотограмметричного блоку. У нашому трактуванні ці зображення опорних точок та їхнього оточення на місцевості називають “опорні образи”. Основою роботи є розроблення способу отримання опорних образів з допоміжних аерознімків і перенесення цих образів на основні аеро- або космічні знімки місцевості засобами комп‘ютерного стереоототожнення. Для досягнення поставленої мети ми розробили спосіб опрацювання для створення опорних образів аерознімка чи серії допоміжних різномасштабних аерознімків, отриманих дроном з різних висот над опорною точкою. Оператор опізнає точку один раз на допоміжному аерознімку найвищого розрізнення. Далі відбувається автоматичне стереоототожнення опорного образу на всій серії допоміжних знімків послідовно із зменшенням розрізнення і в кінцевому результаті – безпосередньо на аерознімках фотограмметричного блоку. Ніяких опізнавань/наведень курсора оператором-людиною і пов’язаних з ними розбіжностей, промахів і помилок не відбувається. Крім того, вказаний метод при застосуванні достатньо великого розміру образів-еталонів можна застосовувати на малоконтурній місцевості і тому можна обійтись в багатьох випадках без фізичного маркування точок. А це шлях до спрощення і здешевлення фотограмметричної технології. Дію розробленого способу перевірено експериментально для забезпечення опорною інформацією блоку архівних аерофотознімків малоконтурної місцевості. Результати дослідної апробації запропонованого способу дають підстави стверджувати, що запропонований спосіб дає змогу ефективніше виконувати геодезичне забезпечення фотограмметричних проектів за рахунок відмови від фізичного маркування місцевості перед аерозніманням. Запропонованим способом можна скористатись також для отримання контрольної інформації для перевірки якості фотограмметричного знімання. Автори стверджують, що застосування додаткового обладнання – БПЛА напівпрофесійного класу для отримання опорних образів є економічно обгрунтованим. **Наукова новизна та практична значущість.** Вперше викладено результати апробації методу «опорного образу» з отриманням стереопар аерознімків з вертикальним розміщенням базису знімання. Виконане дослідження властивостей таких стереопар аерознімків для отримання зображень опорних точок. Показано дієвість включення опорних образів в основний блок мережі цифрової фототріангуляції для знімків, отриманих з БПЛА.

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

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