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ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ

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ИЗВЕСТИЯ

РОО «НАЦИОНАЛЬНОЙ
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ASSESSMENT OF THE ACCURACY OF THE GEOMETRIC SCHEME OF GCPS WHEN CREATING DSM USING UAV

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Abstract. This article is dedicated to studying the aspects of using Unmanned Aerial Vehicles (UAVs) for topographic surveys in production, specifically evaluating the impact of ground control points on the accuracy of generated digital terrain models (DTMs). A comparative analysis was conducted to assess the accuracy of coordinate determination from DJI Mavic 2 Pro drones and DJI Mavic 2 Pro Post Processing Kinematic (PPK) TOPODRONE, which utilizes a multi-frequency Global Navigation Satellite System (GNSS) receiver for precise positioning of image centers.

Based on the collected imagery, DTMs were generated using Agisoft Metashape Professional software with different configurations of ground control point placement and density using ground markers.

As a result of analyzing the generated DTMs, the main advantage of using the PPK method was identified, which showed a significant increase in the distance between ground control points, resulting in a reduced number of markers, decreased point density, and reduced overall fieldwork, thus reducing financial and time costs. Analytical dependencies for determining the sufficient number of ground markers for any required area and the optimal distance between markers depending on the desired resolution of the DTM were derived from the analysis. These dependencies can be applicable in practice for UAV aerial photography production and for further research in this field. The authors plan to continue their research in this direction to optimize the preparatory work for aerial photography production.

Key words: unmanned aerial vehicle, planned-high-altitude justification, digital model, ground marker, Post Processing Kinematic, mathematical assessment of accuracy.

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ҰҰА ҚОЛДАНА ОТЫРЫП ЖЦМ ҚҰРУ КЕЗІНДЕ ТІРЕК МАРКЕРЛЕРІНІҢ ГЕОМЕТРИЯЛЫҚ СХЕМАСЫНЫҢ ДӘЛДІГІН БАҒАЛАУ

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Аннотация. Бұл мақала топографиялық түсірілім өндірісінде ұшқышсыз ұшу аппараттарын пайдалану аспектілерін зерттеуге, атап айтқанда жер үсті Жоспарлы-биіктік негіздемесінің жергілікті жердің цифрлық модельдерінің дәлдігіне әсерін бағалауға арналған. Зерттеуді орындау үшін DJI Mavic 2 Pro және DJI Mavic 2 Pro Post Processing Kinematic (PPK) TOPODRONE

ұшқышсыз ұшу аппараттарынан (ҰҰА) алынған координаттарды анықтау дәлдігіне салыстырмалы талдау жүргізілді. Қосымша Post Processing Kinematic модулі (көп жиілікті GNSS қабылдағыш) кескін орталықтарының нақты координаттарын анықтауға мүмкіндік береді.

Жиналған фотоматериал негізінде Agisoft Metashape Professional бағдарламалық жасақтамасында жер бетіндегі маркерлер түріндегі тірек желісінің орналасуы мен тығыздығының әртүрлі геометриясын қолдана отырып, жердің сандық модельдері (ЖСМ) жасалды.

Құрылған жер бедерінің цифрлық модельдерін (ЖСМ) талдау нәтижесінде Post Processing Kinematic әдісін қолданудың негізгі артықшылығы анықталды, ол тірек маркерлер арасындағы қашықтықты едәуір ұлғайтудан тұрады, бұл олардың санының айтарлықтай төмендеуіне, желінің сирек болуына және далалық жұмыстардың жалпы көлемінің төмендеуіне, яғни қаржылық және уақыт шығындарының төмендеуіне әкеледі. Маркерлер арасындағы қашықтықтың әсерін талдау барысында кез-келген қажетті аймаққа маркерлердің жеткілікті санын және құрылған рельеф моделінің қажетті ажыратымдылығына байланысты маркерлер арасындағы қажетті қашықтықты анықтау үшін аналитикалық тәуелділіктер алынады. Бұл тәуелділіктер ұшқышсыз аэрофототүсірілім жасау тәжірибесінде қолданылуы мүмкін, сондай-ақ осы саладағы қосымша зерттеулер үшін пайдаланылуы мүмкін. Авторлар аэрофототүсірілім өндірісі үшін дайындық жұмыстарын оңтайландыру үшін осы бағыттағы зерттеулерді жалғастыруды жоспарлап отыр.

Түйін сөздер: ұшқышсыз ұшу аппараты, жоспарлы-биіктік негіздемесі, жер бедерінің цифрлық моделі, жердегі маркерлер, Post Processing Kinematic, дәлдікті математикалық бағалау.

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ОЦЕНКА ТОЧНОСТИ ГЕОМЕТРИЧЕСКОЙ СХЕМЫ ОПОРНЫХ МАРКЕРОВ ПРИ СОЗДАНИИ ЦММ С ПРИМЕНЕНИЕМ БПЛА

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Аннотация. Данная статья посвящена исследованию аспектов использования беспилотных летательных аппаратов при производстве топографической съемки, в частности оценке влияния наземного планово-высотного обоснования на точность создаваемых цифровых моделей местности. Для выполнения исследования проведен сравнительный анализ точности определения координат, полученных с беспилотных летательных аппаратов (БПЛА) DJI Mavic 2 Pro и DJI Mavic 2 Pro Post Processing Kinematic (PPK) TOPODRONE. Дополнительный модуль PPK (мультичастотный GNSS приемник) позволяет определять точные координаты центров снимков.

На основе собранного фотоматериала в программном обеспечении Agisoft Metashape Professional созданы цифровые модели местности (ЦММ) с использованием различной геометрии расположения и плотности опорной сети в виде наземных маркеров.

В результате анализа созданных цифровых моделей местности (ЦММ) определено основное преимущество использования метода Post Processing Kinematic, которое заключается в значительном увеличении расстояния между опорными маркерами, что приводит к существенному снижению их числа, разрежению сети и уменьшению общего объема полевых работ, т.е. снижению финансовых и временных затрат. В процессе анализа влияния расстояния между маркерами получены аналитические зависимости для определения достаточного числа маркеров на любую требуемую площадь и необходимого расстояния между маркерами в зависимости от требуемого разрешения создаваемой модели местности. Данные зависимости могут быть применимы в практике производства беспилотной аэрофотосъемки, а также использованы для дальнейших исследований в данной области. Авторы планируют продолжить исследования в данном направлении для оптимизации подготовительных работ для производства аэрофотосъемки.

Ключевые слова: беспилотный летательный аппарат, планово-высотное обоснования, цифровая модель местности, наземные маркеры, Post Processing Kinematic, математическая оценка точности.

Introduction. Unmanned digital imaging is the perspective, actively developing technology, applied in execution of geodesics, surveying, cadaster works and mapping of different level of complexity (Rafael Bailon-Ruiz, et all, 2022; Salvini, et all, 2018). It has enormous potential, which actively expands the spheres of application. One of main aspects for creation of detailed dimensional digital terrain model is the definition of parameters for photogrammetric calibration. Calibration of elements of interior orientation is made on the basis of ground points (markers), which allows reaching of higher level of accuracy in height and on plane. Definition of focal distance in calibration process is one of key elements of model calculation at photographic operations. The goal of decision is to define the influence of geometric location of supporting markers on inaccuracy in digital terrain model at performing of unmanned aerial photography applying different equipment.

The study was performed in quarry located in Central Kazakhstan, which was under long-term conservation. At the moment, quarry is gone to ground water. In 2019 water pumping and reclamation were started. In the process of pumping, the need appeared to refresh the plan of mining operations for underlying drowned horizons. High water content of rock massif in the territory of quarry resulted the impossibility to execute this work by traditional methods. Lower horizons of quarry were unavailable for direct in-situ measurements of bench crests using tacheometer or GNSS equipment (Beregovoi, et all, 2017; Dorokhov, et all, 2018), applying methods of radar interferometry (Ozhigina, 2016) was impossible as well. Aerial photography using unmanned aerial vehicles (UAV) was the only possible way to execute this work (Giordian, et all, 2017; Koukouvelas, et all, 2020; Ozhygin, et all, 2021); at that, coordination of supporting ground markers was made by GNSS equipment in safe areas, in considerable distance from drowned areas.

Materials and main methods of research. To define the parameters of photogrammetric calibration and sufficient number of supporting ground markers, the study included two types of aerophotogrammetric systems with similar unmanned aerial vehicle DJI Mavic 2 Pro:

1) The first flight was made with DJI Mavic 2 Pro drone in standard trim by DJI company. This drone has long flight time (31 minutes) due to small size and special structure with proper aerodynamics. In standard trim, DJI Mavic 2 Pro has the camera of 4K (5472×3648pix) and navigation receiver, which records in GPS system, with accuracy 3 to 10 m, which allows drone to orientate in space and make flight along the pre-defined route.

2) The second flight was made by DJI Mavic 2 Pro Post Processing Kinematic (PPK) drone with installed geodesic upgrade by TOPODRONE. This upgrade is composed of miniature multisystem and multifrequency satellite receiver, which allows to define the position of drone in the air in the moment of photo shooting with accuracy up to centimeters (picture 1).

On the basis of two flights done, applying different parameters of photogrammetric calibration, it is possible to define the number of supporting ground markers, necessary and sufficient for best results (Sanz-Ablanedo, et all, 2018). Notify that using drone with geodesic upgrade causes more precise results. For photogrammetric calibration, the information on points determination in space, presented in pictures, and their coordinates in three-dimensional space. This information is used for definition of internal and external parameters of camera, which gives the opportunity of correct projection of the image on plane and definition of geometric characteristics of objects.

Number of supporting ground markers, necessary for sufficient calibration, depends on number of factors, such as resolution and elevation angle of camera, vegetation cover of earth surface, etc. Thus, to define the optimal number of markers and parameters of photogrammetric calibration, it is necessary to consider the peculiarities of definite location and goal of study, and select the corresponding aerophotogrammetric system depending on required accuracy and resources (Benassi, et all, 2017).

Volume coordinates of drone position in the air in the moment of photo shooting, is one of main piece of information necessary orientation of photos relative to each other during the whole route of drone flight and for further creation of digital terrain model and orthophotoplan of the location. Despite the type of applied UAV, presence of ground traverse is necessary, because it plays the key role in calibration of focal distance of camera.

1- Condition of power module; 2-Quality of received GNSS signal;
3- Condition of record on memory card; 4-Presence of inaccuracies in the system;
5-Socket for micro SD; 6- Dual-frequency (L1/L2) antenna

Picture 1 – DJI Mavic 2 Pro PPK TOPODRONE

Thus, necessary condition for efficient unmanned digital imaging is the creation of horizontal and vertical photo-control of due quality. Horizontal and vertical survey in the object was created using geodesic satellite receiver Leica GS14 in differential measuring mode. The accuracy definition of center of ground labels amounted 1-2 cm on plane and 2 cm vertically.

In the process of creation of digital terrain models (DTM) on the basis of the first flight, main basic data for UAV camera calibration, were the coordinates of ground traverse (Oniga, V.-E. and et all, 2020). At the second flight, main role in orientation of DTM was assigned on exact definition of picture center, made according to the method of Post Processing Kinematic (PPK), due to geodesic upgrade by TOPODRONE (Bolkas, 2019).

To replace the metadata of navigation coordinates of pictures with highly accurate coordinates obtained by PPK method, special software was used, presented by TOPODRONE – TOPOSETTER. Thus, DTM was created on the basis of shots with exact centers, which gives the opportunity to model to have correct vertical and horizontal coordinates before the correction process in reference to ground traverse. At that, vertical exactness of this DTM will be lower by several digits compared to plan, through uncertainty of camera focal distance. To increase the vertical accuracy, the calibration is made in reference to fixed ground markers, located on natural location.

Results of research. To process the complex of geospatial data obtained from two types of UAV, the software Agisoft Metashape Professional was applied.

The first stage of processing of geospatial data is aerial triangulation, where the position and spatial orientation is defined for each photo. This is made by definition of points and lines in space, which are marked on photo and then connected to three-dimensional space. After that, the expanded point cloud is created by finding peculiar points on each photo. Peculiar points are unique features of the photo, which might be used for identification of the photo and its position in three-dimensional space. For example, peculiar point might be the angle of the building or some special part of landscape, which is emphasized on the photo. After finding peculiar points on each photo, the software defines the points, coinciding between photos.

In the result of this process, photos are oriented relatively to each other, considering their spatial geotagging. Agisoft Metashape Professional gives the opportunity to polarize photos regarding their common pixels, due to line overlap of photos by 80% and lateral overlap by 70%. On the basis of software algorithm, peculiar points (peculiarities) of each photo are defined on the basis of common pixels; they are considered in the current stage of processing for creation of expanded point cloud. At processing, the number of peculiar points (peculiarities) and number of possible point projections are pre-defined, which are found in common photos. Too high or too low parameter value may cause the loss of some part of dense point cloud or to excessive noise. Agisoft Metashape Professional software calculates the depth maps only for those pairs of photos where the number of correspondences if higher than pre-defined limit. This limit is 100 correspondences or 10% of maximal number of correspondences between this photo and other photos of the project. Thus, the expanded point cloud is composed. Depending on applied equipment complex (with PPK and without PPK), details of reproduction of expanded point cloud do not vary.

The second step of geospatial data processing is in spatial reference of expanded point cloud. Expanded point cloud is composed of photos with fixed navigation coordinates. However, these coordinates might be not enough exact for creation of high-precision DTM. That is why it is necessary to make spatial reference, to reach the required accuracy. Spatial reference of digital terrain model may vary depending on UAV packaging. For example, at creation of DTM without using precise photo centers, the key role is played by horizontal and vertical survey of aerial photography, which is represented with ground markers. These markers are set on the ground and their exact geodesic coordinates are defined beforehand.

In the process of reference using precise photo centers (PPK), navigation coordinates of photos are replaced with more precise ones, obtained by calculation under PPK method. Thus, horizontal and vertical survey on the ground is used in combination with precise coordinates of photo centers.

The third step is in creation of dense point cloud. To get the dense point cloud, Metashape applies algorithms that combine the data from different angles and positions, to create the maximally precise object model. These algorithms eliminate mistakes as well, which may appear at data processing, and give the opportunity to obtain the most precise point cloud.

After creating dense point cloud, we can move to another stage of DTM creation, which includes the creation of texturized 3D-model, and then generation of DTM itself (picture 2).

The area of studies object amounts 80 hectares. The height of flights amounted 140 meters at DTM resolution of 2,52 cm/px. In this work, the distance between supporting markers is measured using pixels (px), because depending on detailing (afield pixel dimension) the flight height is changed. The higher is the flight, the bigger is the pixel (afield), which results the increase of distance between supporting markers in designed network, and vice versa.

To define the influence of geometry of horizontal and vertical survey of aerial photography (location of ground markers and their number) on accuracy of created digital terrain models, the supporting markers were positioned in the area of 80 hectares, in amount of 1 to 15, and the comparative analysis was made with accuracy estimation, considering different geometric positioning and number of supporting markers (Agüera-Vega, et all, 2018). The obtained models created with PPK method and without it, were separated subject to number of uncertainties in the plan. Thus, three categories were defined:

«c» category – large uncertainty (over 150mm);

«b» category – moderate uncertainty (150mm to 50mm);

«a» category – small uncertainty (below 50mm).

All the values of uncertainties in measurements, related to geospatial data, are measured and estimated in reference to exact positions of supporting markers on ground, which are main starting points and are compared to digital terrain model.

Picture 2 – Digital model of the location

Processing results for digital terrain models are presented in table 1.

Table 1 – Processing results for digital terrain models

Number of markers	Uncertainties in axles			Planned displacement, mm	Vector displacement, mm	Distance between markers, m	Distance, px
	X, mm	Y, mm	Z, mm				
Processing results, PPK excluded							
3	420	387	579	571	813	582	23095
4	346	160	420	381	567	504	20000
5	164	129	251	209	326	451	17897
6	130	112	150	172	228	412	16349
7	84	80	135	116	178	381	15119
8	77	75	122	107	163	356	14127
9	75	68	107	101	147	336	13333
10	73	60	95	94	134	319	12659
11	65	55	82	85	118	304	12063
12	51	44	67	67	95	291	11548
13	32	35	55	47	73	279	11071
14	25	20	43	32	54	269	10675
15	23	19	32	30	44	260	10317
Processing results, PPK included							
1	110	213	99	240	259	-	-
2	98	150	85	179	198	713	28294

3	84	89	82	122	147	582	23095
4	79	74	76	108	132	504	20000
5	65	68	72	94	118	451	17897
6	54	55	45	77	89	412	16349
7	40	27	15	48	51	381	15119
8	37	24	15	44	47	356	14127
9	36	20	13	41	43	336	13333
10	30	20	13	36	38	319	12659
11	30	18	11	35	37	304	12063
12	27	16	11	31	33	291	11548
13	25	15	10	29	31	279	11071
14	20	15	9	25	27	269	10675
15	12	10	9	16	18	260	10317

Analysis of accuracy estimation of digital terrain models, considering different geometric positioning and number of supporting markers showed the following:

- at creation of DTM using DJI Mavic 2 Pro in standard trim by DJI (without PPK) it is necessary to have minimum 3 supporting markers, which form the plane together; «c» category (large uncertainty – red color) takes place at using 3 to 8 markers, distance between markers amounts 582 ÷356m respectively, the planned uncertainty is within range of 107mm (at 8 markers) ÷571mm (at 3 markers), height uncertainty amounts 122 mm (at 8 markers) ÷ 579 mm (at 3 markers), spatial uncertainty is increased from 163mm up to 813mm in accordance with decrease of number of markers; «b» category (moderate uncertainty – amber color) takes place at use 9 to 13 markers, distance between markers amounts 336÷279m respectively, maximal deviations in plan reach 101 mm (at 9 markers), minimal ones – 47 mm (at 13 markers), height uncertainty has dynamic pattern of 55mm (при 13 markers) to 107mm (at 9 markers), and spatial uncertainty is changed within the range of 73mm to 147mm at decrease of number of markers from 13 to 9; «a» category (small uncertainty – green color) is reached at number of markers of 14 and more, distance between markers up to 269m, uncertainty in plan up to 32 mm, height uncertainty amounts 43mm - at 14 markers, 32mm – at 15. Vector displacement of model in reference to control markers at 14 markers in this case is equal to 54 mm, at 15 - 44 mm;

- at creation of DTM using DJI Mavic 2 Pro with installed PPK module, there shall be no less than 1 supporting marker, for exact vertical bridging of expanded point cloud, the calibration of focal distance (f) is necessary in reference to ground markers, at that, the more supporting markers are used in calibration of focal distance, the more accurate is f value; at accuracy analysis of digital terrain model, created using DJI Mavic 2 Pro with installed PPK module, category corridors for uncertainties rate in the plan vastly differ from previous option, without using PPK: «c» category (large uncertainty – red color) includes models, where no more than 2 markers were used at processing, distance between markers amounts 713 m, planned uncertainty at use of 1 marker reaches 240mm, at use of 2 markers

– 179mm, height uncertainty is measured from 99mm - at 1 marker up to 85mm - at 2 ones, spatial uncertainty amounts 198÷259mm; «b» category (moderate uncertainty – amber color) includes models, where 3 to 6 markers were used during the processing, distance between markers amounts 582m (at 3 markers) ÷ 412m (at 6 markers), uncertainty in plan is decreased respectively from 122mm till 77mm at increase of markers from 3 to 6, height uncertainty is within the range of 82mm (at 3 markers) ÷ 45mm (at 6 markers), spatial uncertainty is changed within the range from 89mm (at 6 markers) to 147mm (at 3 markers); «a» category (small uncertainty – green color) at use of PPK technology is reached at use of 7 markers, compared to the option without PPK, such level of accuracy was reached at use of 14 markers only, distance between markers amounts 381m (at 7 markers) ÷ 260m (at 15 markers), uncertainty in plan is decreased from 48mm to 16mm at increase of markers from 7 to 15, height uncertainty amounts 15mm at 7 markers and 9mm at 15 ones, spatial uncertainty is changed respectively within the range from 51mm to 18mm at 7 and 15 markers.

Thus, at increase of number of ground markers, involved in creation of DTM, the accuracy of model is being increased constantly. This is influenced by position of markers, as well as by distance between them. The distance relationship between markers is tracked, which directly influences the accuracy measurement for the model.

At increase of number of supporting markers, involved in model processing, distance between them is decreased, which positively influences the accuracy of the model. At that, influence of each following marker in the processing becomes less, but general trend to accuracy increase remains positive.

This observation results the logic conclusion that there is the relationship between accuracy, number of markers and area of the object (distance between markers). This relationship may be expressed in form of markers sufficiency coefficient per defined area:

$$k = \frac{M}{S}, \qquad (1)$$

where M – number of markers;

S– area of the object, hectares.

Calculation of sufficiency coefficient at use of supporting ground markers only:

$$k = \frac{14}{80} = 0{,}175\text{ha}$$

Calculation of sufficiency coefficient at use of coordinates of photo centers and ground markers:

$$k = \frac{7}{80} = 0{,}088\text{ha}^{-1}$$

These values are suitable for use of photographic equipment matrix of 20 Mpx with resolution ability on ground 2,52 cm/px. In case of increase of pixel dimension, coefficient (k) will be decreased.

The results of experiment may also disclose the range of distances between markers, where the geometry of support ground network will be sufficient for digital terrain model of high accuracy.

Considering the resolution of shooting during the study (2,52 cm/px), we can convert this effective distance to pixels:

$$Lpx = \frac{L}{a}, \qquad (2)$$

где Lpx– distance between supporting marks in pixels,
L– distance between supporting marks in centimeters,
a – resolution cm/px.

At use of ground markers only, efficient distance in pixels for reaching of accurate results is calculated as follows:

$$Lpx = \frac{26900}{2,52} = 10675px$$

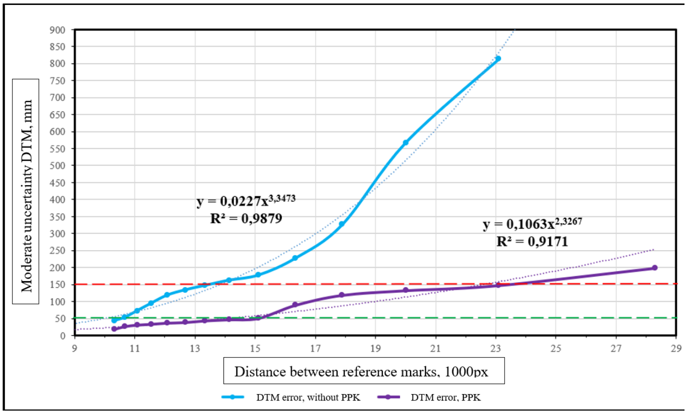
At use of coordinates of photo centers and ground markers, efficient distance in pixels is calculated as follows:

$$Lpx = \frac{38100}{2,52} = 15119px$$

According to the results of data in Table 1, the graph of dependence of distance between supporting marks and uncertainty of digital terrain model was constructed (picture 3).

In the result it was found that at absence of precise photo centers distance between supporting markers shall be no less than 10 675px, and at use of PPK method, the distance between supporting markers reaches 15 119px.

Thus, main advantage of PPK method application is in significant increase of distance between supporting markers, which results the decrease of their amount and total scope of field works, which, in turn, decreases financial and time expenditures (Hugenholtz C. 2016).



Picture 3 – Schedule of dependence of DTM uncertainty
on geometric location of support labels

Discussion. Use of unmanned digital imaging is the efficient and safe method for execution of geodesics, surveying, cadaster works and mapping in conditions when in-situ measurements are impossible or hazardous for people. Unmanned systems may be applied for photo shooting in inaccessible or hazardous areas. However, to reach the high accuracy of digital terrain model, it is necessary to make the system calibration and define the focal distance, which requires the use of ground points (markers). As well, correct positioning of supporting markers and their coordinate labeling using GNSS equipment is the important aspect.

Importantly, that use of unmanned systems of aerial photography decreases the risk of uncertainties related to human factor. Besides, unmanned systems may cover bigger areas and make photo shooting within shorter period, which increases the efficiency of work and decreases costs.

Use of UAV to obtain geospatial data and creation of digital terrain models on their base comprises new approach to obtaining of precise and high-quality data for solving of number of urgent problems on high level. This might be useful for different industries, such as geodesy, construction, geology, ecology, etc.

For example, at design of buildings and infrastructure objects it is necessary to have exact data on landscape and other peculiarities of location. Digital terrain models, obtained with unmanned aerial vehicles, may present these data with high resolution and accuracy, which may decrease risks at design and construction.

In geology and ecology, digital terrain models may be used for study of changes of earth surface and its condition in different times. For example, change of landscape or vegetative cover may certify the climate change or man-made impact on the environment (Rafael Bailon-Ruiz and et all, 2022; Tseshkovskaya, et all, 2019).

As well, digital terrain models might be used for creation of virtual media for learning and training, such as flight stimulators, which might be useful for training of pilots and other specialists.

In general, use of unmanned aerial vehicles to obtain geospatial data and creation of digital terrain models and objects, comprises the important and perspective approach, which might be widely used in different industries and scientific spheres.

Conclusion. One of main conditions for creation of accurate digital terrain models use of supporting markers. However, application of markers requires significant costs for their installation and maintenance. Besides, installation of markers in several areas might be complicated.

In the process of study, analytical dependences were obtained, which allow defining the range of sufficiency of markers for any required area and necessary distance between markers depending on required resolution of created digital terrain model. This gives the opportunity to optimize the works in creation of horizontal and vertical survey to make the aerial photo shooting using UAV.

In the result of analysis of created digital terrain models it was defined that application of Post Processing Kinematic method gives the opportunity to decrease the number of necessary supporting ground markers more than by *50%* and increase the distance between markers by *41%*. During the analysis of influence of distance between markers, authors disclosed the analytical dependences to define the range of sufficiency of markers for any required area and necessary distance between markers depending on required resolution of created digital terrain model. These dependences might be practically used in unmanned aerial photography, and further applied for studies in this area.

It is suggested that study of relative position of markers may result the definition of optimal configuration of markers, which ensures the best quality and accuracy of created digital terrain models at minimal amount of markers and resources. As well, authors may consider the opportunity to apply other methods, such as Real Time Kinematic, for future increase of accuracy of created models of the area.

Further study in the sphere of relative positions of markers may result the definition of optimal configuration of markers, which ensures the best quality and accuracy of created models of the area at minimal amount of markers and resources. This may significantly increase the efficiency of unmanned aerial photography and decrease the expenses for measurements. Authors plan to continue the scientific researches in this sphere, targeted to definition of role of relative position of markers in change of quality and accuracy of created models of the area**.**

References

Agüera-Vega F., Carvajal-Ramírez F., Martínez-Carricondo P. (2017). Assessment of UAV-photogrammetric mapping accuracy based on variation of ground control points. International Journal of Applied Earth Observation and Geoinformation, 72, 1–10. (in Eng.)

Benassi F., Dall'Asta E., Diotri F., Forlani G., Morra di Cella U., Roncella R., Santise M. (2017). Testing accuracy and repeatability of UAV blocks oriented with GNSS-supported aerial triangulation. Remote Sensing, 9, 172. (in Eng.)

Beregovoi D.V., Younes J.A., Mustafin M.G. (2017). Monitoring of Quarry Slope Deformations with the Use of Satellite Positioning Technology and Unmanned Aerial Vehicles. Procedia Engineering, 189, 737-743. (in Eng.)

Bolkas D. (2019). Assessment of GCP Number and Separation Distance for Small UAS Surveys with and without GNSS-PPK Positioning. Journal of Surveying Engineering, 145, 04019007. (in Eng.)

Bailon-Ruiz R., Bit-Monnot A., Lacroix S. (2022). Real-time wildfire monitoring with a fleet of UAVs. Robotics and Autonomous Systems, 152, 104071. (in Eng.)

Dorokhov D.V., Nizametdinov F.K., Ozhigin S.G., Ozhigina S.B. (2018). A Technique for Surveying of Ground Surface Deformations in Mine Field. Journal of Mining Science, 54(5), 874-882. (in Eng.)

Giordian D., Manconi A., Remondino F., Nex F. (2017). Use of unmanned aerial vehicles in monitoring and application and management of natural hazards. Geomatics, Natural Hazards and Risk, 8, 1–4. (in Eng.)

Hugenholtz C., Brown O., Walker J., Barchyn T., Nesbit P., Kucharczyk M., Myshak S. (2016). Spatial accuracy of UAV-derived orthoimagery and topography: Comparing photogrammetric models processed with direct geo-referencing and ground control points. Geomatica, 70, 21–30. (in Eng.)

Koukouvelas I.K., Nikolakopoulos K.G., Zygouri V., Kyriou A. (2020). Post-seismic monitoring of cliff mass wasting using an unmanned aerial vehicle and field data at Egremni, Lefkada Island, Greece. Geomorphology, 367, 107036. (in Eng.)

Oniga V.-E., Breaban A.-I., Pfeifer N., Chirila C. (2020). Determining the suitable number of ground control points for UAV images georeferencing by varying number and spatial distribution. Remote Sensing, 12, 876. (in Eng.)

Ozhigina S.B., Mozer D.V., Ozhigin D.S., Ozhigin S.G., Bessimbayeva O.G., Khmyrova E.N. (2016). Monitoring of the undermined territories of Karaganda coal basin on the basis of satellite radar interferometry. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 3, 37–40. (in Eng.)

Ozhygin D., Šafář V., Dorokhov D., Ozhygina S., Ozhygin S., Staňková H. (2021). Terrestrial photogrammetry at the quarry and validating the accuracy of slope models for monitoring their stability. IOP Conference Series: Earth and Environmental Science, 906(1), 012062. (in Eng.)

Salvini R., Mastrorocco G., Esposito G., Di Bartolo S., Coggan J., Vanneschi C. (2018). Use of a remotely piloted aircraft system for hazard assessment in a rocky mining area (Lucca, Italy). Natural Hazards and Earth System Sciences, 18, 287–302. (in Eng.)

Sanz-Ablanedo E., Chandle J.H., Rodríguez-Pérez J., Ordóñez C. (2018). Accuracy of unmanned aerial vehicle (UAV) and SfM photogrammetry survey as a function of the number and location of ground control points used. Remote Sensing, 10, 1606. (in Eng.)

Tseshkovskaya Ye.A., Golubeva E.I., Tsoy N.K., Oralova A.T., Matonin V.V. (2019). Geoekologicheskie aspekty rekul'tivacii narushennyh zemel' v Karagandinskoj oblasti (Respublika Kazahstan). [Geoecological aspects of disturbed lands reclamation in the Karaganda region (The Republic of Kazakhstan)]. Vestnik Moskovskogo Universiteta, Seriya 5: Geografiya, 2019(4), 73-80. (in Rus)

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