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ERROR ESTIMATION OF DEM OF ORTHOTRANSFORMATION OF AERIAL IMAGES OBTAINED FROM UAVS ON THE MOUNTAINOUS LOCAL SITE IN THE VILLAGE SHIDNYTSYA

The aim of the work is to estimate the error of the ortho rectification of aerial images obtained by unmanned aerial vehicle for a mountain site in the village Shidnytsya with the help of additional grid of points obtained by GNSS-survey. The task is to analyse the difference between the heights of the points obtained using two methods: using the map of heights from the UAV survey and using data of GNSS-survey and then to estimate the difference between the real coordinates of the ground control points with their coordinates on the orthophoto plan. **The method.** It is proposed to use the method of ortho rectification of aerial images obtained by UAV on mountainous terrain for determination of the real value of height error. A local test site with size approximately 70×60 meters was created on the hill in the village Shidnytsya, The site is part of terrain covered by a general aerial survey of the village. On this site an additional GNSS-survey was implemented and a grid of points with measured coordinates was generated with step one meter. Processing of the obtained ortho image height map based on the data of the aerial survey of the entire Shidnytsya and the results of GNSS-survey was realized in the software of ArcGIS. Layer of points of the local test site was overlaid on the aerial image and then this data were compared with the coordinates of the same points obtained from the map of heights. **Results**. Comparing the height values of 87 points on the test site to the height values of the same points obtained from the map of heights created on the basis of aerial survey implemented by unmanned aerial vehicle, it was determined that the height values of the points are not very different. The root mean square error is 0.39 m. **Scientific novelty. T**he method of comparing the values of terrain point heights obtained using different technologies for determination of the value of the error of ortho rectification of aerial images obtained by UAV on mountainous local site near the village Shidnytsya is proposed. **Practical significance.** The obtained results of error values of aerial images ortho rectification show that ortho rectification of aerial images of some mountainous areas obtained using the UAV is in the zone of tolerance.

Key words: ortho rectification, orthophoto plan, aerial survey, UAV, GNSS survey, determination of error value.

Introduction

In the modern world, ultra-light unmanned aerial vehicles (UAVs), different in type, size, and installed equipment, are being used increasingly to solve civil problems of monitoring the territory from the air, in cartography and aerial photography for creation of topographic maps. Unmanned aerial vehicles allow specialists to create orthophotos, matrixes of terrain heights and individual objects in the shortest possible time. Cartography requires the most accurate data and high-quality images that UAVs receive thanks to improved target load on the electromagnetic suspension with stable installation of cameras, regardless of wind gusts and other influencing factors. But how different is the real accuracy of the spatial coordinates of a certain local area in mountainous territory, which is part of a common orthophoto plan? How different is the real local DEM built by survey from DEM created using a height matrix of aerial photography? As it is known, the scale of orthophoto plan depends on focal distance and flight height of UAV. According to these data of our survey it is possible to create orthophoto plan at scale 1:2000. But what is influence of large height differences in mountain terrain when rather small flight height (500 m)? We will try to find the answers to these questions.

Many scientists from Ukraine and abroad deal with researched topic. In Ukraine there is known the works related with accuracy estimation of orthophoto plans created by UAV-survey data of the following scientists. Hlotov V. M., Tserkle-vych A. L., Kolisnichenko V. B., Prokharchuk O. V., Galetsky V. and others [Vovk, et al., 2015; Galetsky, 2012]. The similar to our researches methodology in their works are described by foreign scientists P. Barry, R. Coakley, J. Goncalves, R. Henrikues, Chris Cryderman, S. Bill Mah, Aaron Shufletoski and others [Cryderman, et al., 2014; Barba, 2019; Agüera-Vega, et al., 2017; James, et al., 2017; Goncalves, & Henrikues, 2015; Barry, & Coakley, 2013].

As distinct from the works of above mentioned scientists, our researches are implemented on the site on which there is no control point included in the general rectification of orthophoto plan. Referencing of the researched site with the orthophoto plan is implemented using possibilities of geoinformation analysis.

About the area of research.

Skhidnytsya (Ukrainian: Схі́дниця, Polish: Schodnica) is an urban-type settlement in Lviv Oblast, Western Ukraine. The distance to the regional center of Lviv is 102 kilometres (63 mi), to the Boryslav – 14 kilometers (8.7 mi) and to the Drohobych is 25 kilometers (16 mi).

The town is part of Boryslav Municipality, and represented by local Skhidnytska settlement council with a population of 2.255 (2016 est.) (Fig. 1).

Skhidnytsya is located at an altitude of 600 m (2.000 ft) – 900 meters (3.000 ft) above sea level. The mountains around the town reach a height of 823 m (2.700 ft).

Fig. 1. The area of research on the map

The urban settlement Skhidnytsya was first mentioned in the documents of the 15th century (http://www.shidnitca.com). Skhidnytsya is known for its mineral water deposits. Today there are 38 sources and 17 wells with different chemical composition of mineral water.

The research area is located on a mountain in the western part of Skhidnytsya. The site is “open” (non-afforested) and has an area of 0.9 ha. At the top of the site there are two cell towers. The height difference of the area is 25 meters (Fig. 2).

Aim

The aim of the work is to estimate the error of the ortho transformation of aerial images obtained by unmanned aerial vehicle for a mountain site in the village Shidnytsya with the help of an additional grid of points obtained by GNSS-survey. Using obtained data to propose the scale of orthophoto plan which can be created considering the estimation of heights of independent research site.

Fig. 2. The local research site

The task is to analyse the difference between the heights of the points obtained two ways: using the map of heights from the UAV survey and using data of GNSS-survey, and then to estimate the difference between the real coordinates of the ground control points with their coordinates on the orthophoto plan.

Methodology

For realization of the stated tasks the workflow there was proposed and was implemented step by step (Fig. 5).

The aerial survey was conducted in 2018 by professor Hlotov V.M. together with the specialists of the Ukrainian firm Abris DG at the time of student practice. UAV Arrow was used and the height of the survey was 500 m (Hlotov, at al., 2017). As a result, 400 images were obtained that were processed in Agisoft PhotoScan software and referenced on 94 ground control points, obtained by GNSS (Fig. 3). The final result was the orthophoto map of the territory and the map of heights. It should be emphasized that 94 ground control points were used to create an orthophoto map of the whole Skhidnytsia, and not just our experimental site, which is described in more detail below.

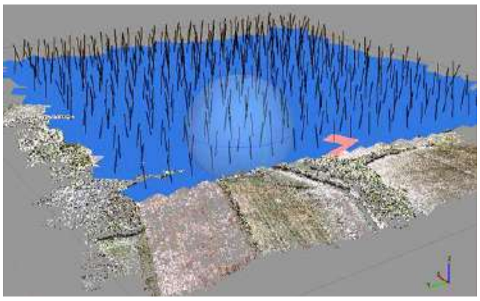


Fig. 3. The process of creation of orthophoto plan in Agisoft PhotoScan environment

During GNSS survey the coordinates of the points were determined in real time (RTK) by dual-frequency GNSS receivers Trimble R7, Leica GX1230GG, and South S82-2013. The survey was carried out from the GeoTerrace Reference Station Network (CORS), owned by the Institute of Geodesy of Lviv Polytechnic National University. (Fig. 4). Reference stations SKOL, SAMB, and STRY located on the distances 25 km, 34 km and 36 km respectively were the closest to the research site.

Fig. 4. The process of obtaining the coordinate of ground control points by GNSS method

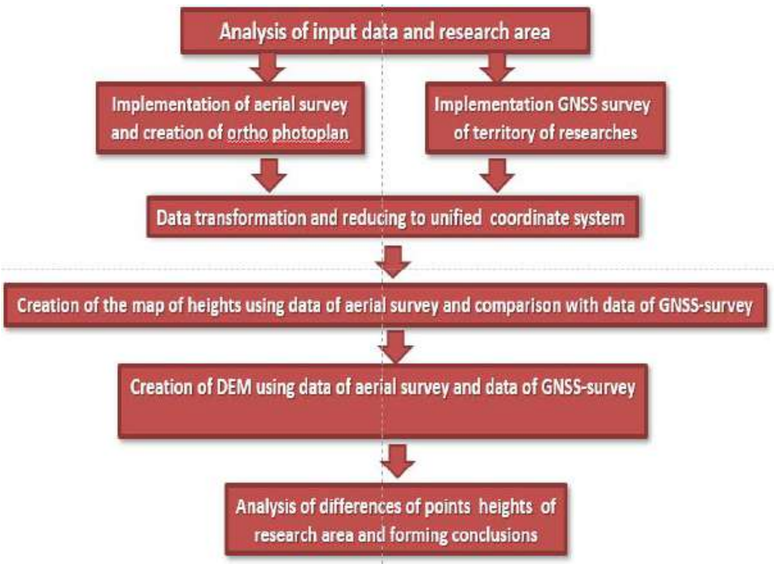


Fig. 5. Technological scheme of error estimation of orthorectification of aerial images

The input data for the research were the matrix of relief heights formed from orthophoto plan [Turner, et al., 2014; Zeitler, W., et al., 2002; Rau, et al., 2002; Saadatseresht, et al., 2015] creation and catalogue of ground control points on the territory of the research site (Fig. 6, 7).

Check points, numbering 87, were obtained by the GNSS survey only for research site and are totally independent and were not used for ortho rectification and creation of the map of the heights.

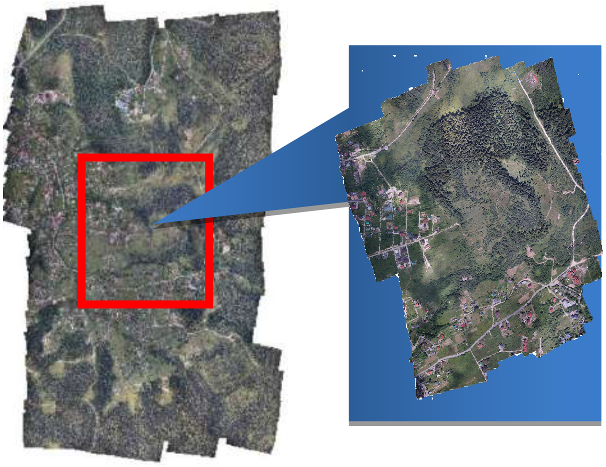
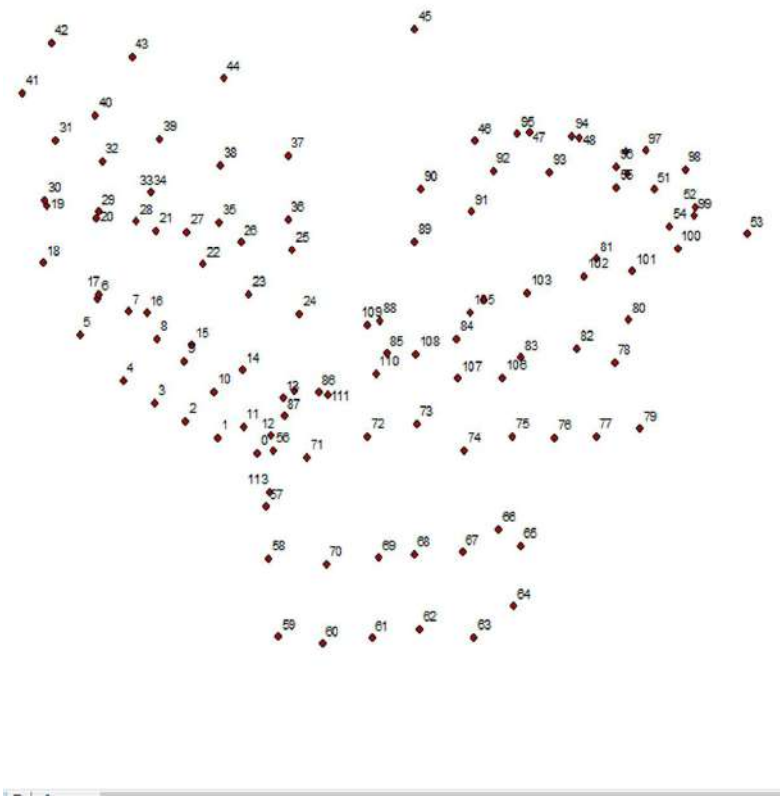
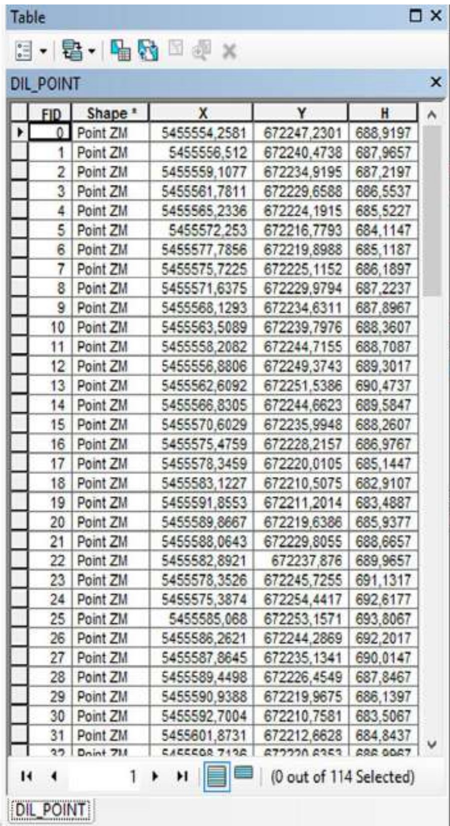


Fig. 6. Orthophoto map of mountain part of Skhidnytsya created in 2018 by data of aerial survey using UAV Arrow developed by Ukrainian company Abris DG. Height of survey is 500 m





Table

DIL_POINT

FID	Shape *	X	Y	H
0	Point ZM	5455554,2581	672247,2301	688,9197
1	Point ZM	5455556,512	672240,4738	687,9657
2	Point ZM	5455559,1077	672234,9195	687,2197
3	Point ZM	5455561,7811	672229,6588	686,5537
4	Point ZM	5455565,2336	672224,1915	685,5227
5	Point ZM	5455572,253	672216,7793	684,1147
6	Point ZM	5455577,7856	672219,8988	685,1187
7	Point ZM	5455575,7225	672225,1152	686,1897
8	Point ZM	5455571,6375	672229,9794	687,2237
9	Point ZM	5455568,1293	672234,6311	687,8967
10	Point ZM	5455563,5089	672239,7976	688,3607
11	Point ZM	5455558,2082	672244,7155	688,7087
12	Point ZM	5455556,8806	672249,3743	689,3017
13	Point ZM	5455562,6092	672251,5386	690,4737
14	Point ZM	5455566,8305	672244,6623	689,5847
15	Point ZM	5455570,6029	672235,9948	688,2607
16	Point ZM	5455575,4759	672228,2157	686,9767
17	Point ZM	5455578,3459	672220,0105	685,1447
18	Point ZM	5455583,1227	672210,5075	682,9107
19	Point ZM	5455591,8553	672211,2014	683,4887
20	Point ZM	5455589,8667	672219,6386	685,9377
21	Point ZM	5455588,0643	672229,8055	688,6657
22	Point ZM	5455582,8921	672237,876	689,9657
23	Point ZM	5455578,3526	672245,7255	691,1317
24	Point ZM	5455575,3874	672254,4417	692,6177
25	Point ZM	5455585,068	672253,1571	693,8067
26	Point ZM	5455586,2621	672244,2869	692,2017
27	Point ZM	5455587,8645	672235,1341	690,0147
28	Point ZM	5455589,4498	672226,4549	687,8467
29	Point ZM	5455590,9388	672219,9675	686,1397
30	Point ZM	5455592,7004	672210,7581	683,5067
31	Point ZM	5455601,8731	672212,6628	684,8437

(0 out of 114 Selected)

DIL_POINT

Fig. 7. Check points network of research area with the table of spatial coordinates obtained by GNSS-survey

Fig. 8 shows applied check points obtained by the GNSS method on the fragment of the orthophoto plan of the research site.

Since the study area is completely covered with grass and shrub vegetation and does not contain any clear contours to identify the points obtained by GNSS survey, there is a problem of possible displacement in their plane coordinates [Zhang, et al., 2017].

In order to eliminate these displacements, it was decided to use the method proposed by Kolb I. Z. in his paper [Kolb, et al., 2013]. The idea is to create maps of flow lines using DEMs created in ArcGIS software by two methods. These maps were necessary to reference the digital elevation model created on the aerial survey data with digital elevation model obtained on additional check points of GNSS survey for research site since it was mentioned early that there was no ground control points on the site when aerial survey was implemented.

Fig. 8. Orthophoto map of mountain part of Skhidnytsya created in 2018 overlapped with check point network obtained by GNSS-survey (all data are referenced to the coordinate system WGS84 and the Baltic Heights)

Based on these maps the same points of line branching are recognized and data referencing is implemented repeatedly (Fig. 9, 10).

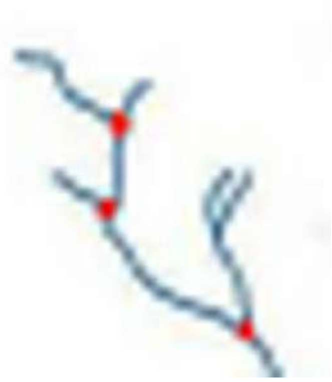


Fig. 9. Map of the flow lines of the research area created on aerial survey data

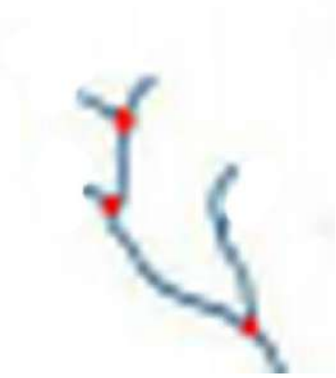


Fig. 10. Map of the flow lines of the research area created on GNSS survey data

Unfortunately, the terrain of the research site is descending, but quite simple. Therefore, after the construction of the flow lines, there were only three suitable points for data matching. But after referencing, the displacements of the points of one model relatively to the other were not significant (up to 0.34 m). This indicates that availability only these three points is sufficient.

After such elimination of plane coordinate displacements we have drawn the check points obtained by GNSS method onto the DSM created from the results of aerial survey. (Fig. 11). Then the differences of height values of check points were preliminary calculated [Barazzetti, et al., 2010; Tarolli, 2014; Chen, et al., 2014].

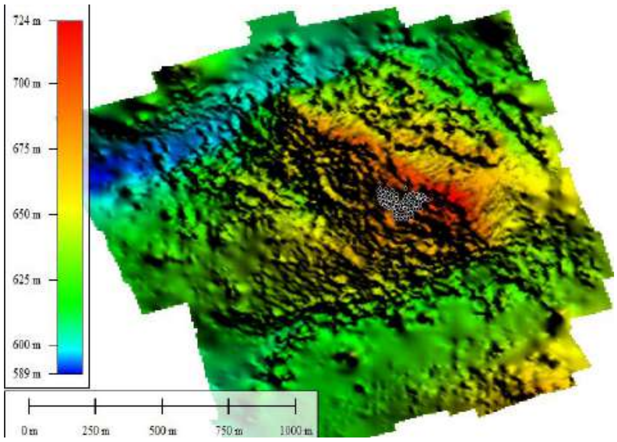


Fig. 11. Map of surface heights created from the results of aerial survey with drawn check points of GNSS-survey in the research area

Based on the digital surface model, it is determined that the heights of the check points in the research area obtained by GNSS-survey vary from the heights obtained by aerial survey within the range 0.11–1.28 m (Fig. 12). This can be explained by the height of the grass cover and shrubs in the research area.

The figure shows the plane coordinates of points – X, У; the heights of these points obtained by GNSS survey and from the map of surface heights constructed by aerial photographs; Δ, m are the difference of the heights of the points obtained by GNSS survey and from the map of surface heights in meters; Δ Δ is the value of Δ, m squared.

Results

Using special filters of the software Agisoft PhotoScan the grass and shrub vegetation was eliminated and DEM created.

Accuracy and density of DEM nodes should provide the determination of the height of the elementary sections of the digital transformed image with error not more than 0.4 mm in the scale of the plan [Parfenova, 2006].

Since the orthophoto plan is created in the scale 1:2000 then:

$$m = 0.4\ mm \times M = 0.04 \times 2000 = 80\ cm = 0.8\ m.$$

According to the formula of Gauss mean square, the error of differences in the point heights was calculated:

$$m = \sqrt{\frac{[v^2]}{n}} = \sqrt{\frac{13.16}{87}} = 0.39\ m.$$

Therefore, the root mean square error for the height of the DEM calculated using 87 check points of the local test area is 0.39 m, which satisfies the condition of 0.8 m (Fig. 13).

	A	B	C	D	E	F
1	X,m	Y,m	H_GNSS,m	H_Aero,m	Δ,m	ΔΔ
2	5455554,258	672247,2301	688,9197	689,82	-0,9003	0,81054
3	5455556,512	672240,4738	687,9657	688,83	-0,8643	0,747014
4	5455559,108	672234,9195	687,2197	688,24	-1,0203	1,041012
5	5455561,781	672229,6588	686,5537	687,4	-0,8463	0,716224
6	5455565,234	672224,1915	685,5227	686,14	-0,6173	0,381059
7	5455572,253	672216,7793	684,1147	685,14	-1,0253	1,05124
8	5455577,786	672219,8988	685,1187	686,14	-1,0213	1,043054
9	5455575,723	672225,1152	686,1897	687,14	-0,9503	0,90307
10	5455571,638	672229,9794	687,2237	688,14	-0,9163	0,839606
11	5455568,129	672234,6311	687,8967	688,41	-0,5133	0,263477
12	5455563,509	672239,7976	688,3607	688,24	0,1207	0,014568
13	5455558,208	672244,7155	688,7087	689,83	-1,1213	1,257314

Fig. 12. Summary table of spatial coordinates of 87 check points of research area obtained from data of aerial and GNSS surveys with calculated height differences (for DSM)

As we can see from Fig. 13, even after applying filters for elimination of the vegetation from the height map, the differences of the point heights still have many, although not large, but negative values. Probably this indicates that the software filters still skip some of the vegetation on the DEM. But considering the small value of these differences, it will not have a strong impact on the results.

Based on the calculated root-mean-square errors of height differences it is possible to create orthophoto plan at the scale 1:2000 with contour section 2 m.

	A	B	C	D	E	F
1	X,m	Y,m	H_GNSS,m	H_Aero,m	Δ,m	ΔΔ
80	5455597,387	672320,3407	707,2405	707,45	-0,2095	0,04389
81	5455590,307	672321,8906	706,8465	707,45	-0,6035	0,364212
82	5455585,315	672319,0276	705,5405	705,45	0,0905	0,00819
83	5455581,84	672311,3237	703,6075	703,46	0,1475	0,021756
84	5455581,141	672303,0902	702,1625	702,46	-0,2975	0,088506
85	5455578,61	672293,324	700,3715	700,46	-0,0885	0,007832
86	5455565,537	672281,5223	696,6295	696,81	-0,1805	0,03258
87	5455569,295	672274,2425	695,8205	696,46	-0,6395	0,40896
88	5455573,653	672265,9199	694,7725	694,82	-0,0475	0,002256
89	5455566,257	672267,4731	694,0435	694,82	-0,7765	0,602952
90	5455563,109	672259,1166	692,3185	692,82	-0,5015	0,251502
91	5455563,767	672253,5236	690,9075	690,82	0,0875	0,007656
92	5455548,346	672249,3065	688,5895	688,82	-0,2305	0,05313
93					-0,7765	13,16375
94						0,151307
95						0,388983

Fig. 13. Summary table of spatial coordinates of 87 check points in the research area obtained from data of aerial and GNSS surveys with calculated height differences (for DEM)

Fig. 14–16 show DEMs of the researched site created on the data of two methods and variograms of height indexes of these DEMs for comparison.

With the variograms (Fig. 15–16) it is possible to see clearly the deviations of the same control points, obtained by the two methods described above.

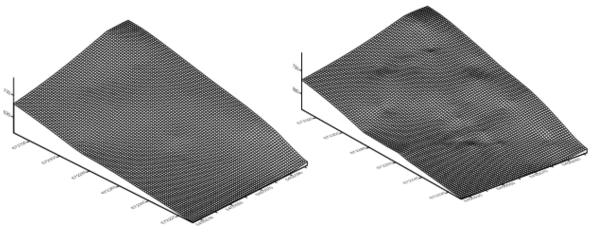


Fig. 14. Created DEMs on the data of aerial and GNSS surveys

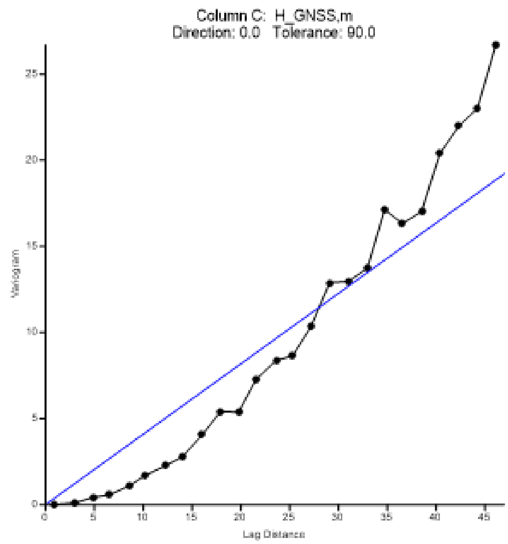


Fig. 15. Variogram of height points of GNSS survey

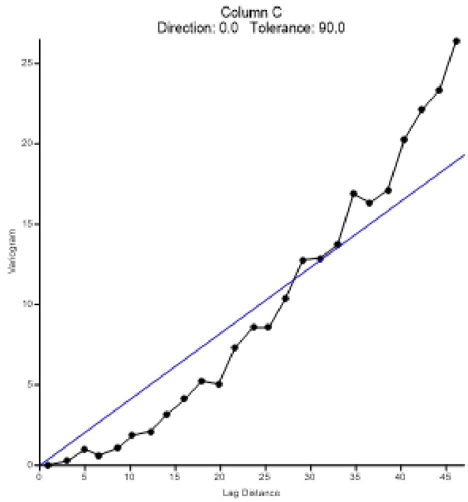


Fig. 16. Variogram of height points of aerial survey

Scientific novelty and practical significance

The method of comparing of the values of terrain point heights obtained using different technologies for determination of the value of the error of ortho rectification of aerial images obtained by UAV on the mountainous local site of the village Shidnytsya is proposed.

The obtained results of error values of aerial images ortho rectification show that ortho rectification of aerial images of researched mountainous area obtained using the UAV is in the zone of tolerance.

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Conclusions

Comparing the heights of 87 check points on the slope of the mountain in Skhidnytsya, obtained by GNSS survey with altitudes of the same points obtained from the map of surface heights created on the basis of UAV aerial survey data, it is determined that the heights of the points are very different within the range from 0.11 m to 1.28 m. This is due to the presence of grass and shrubs on the test area. The mean square error of the deviations is 0.74 m.

After filtering of the map of surface heights, the DEM was obtained. The mean square error of height difference was 0.39 m, which satisfies the condition no more than 0.8 m. Based on the obtained results, we can conclude that the created DEM is appropriate for eliminating the error for relief during transformation of images and creation of an orthophoto plan at the scale 1:2000.

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ВИЗНАЧЕННЯ ПОХИБКИ ЦМР ОРТОТРАНСФОРМУВАННЯ АЕРОЗНІМКІВ, ОТРИМАНИХ ІЗ БПЛА НА ГІРСЬКУ ЛОКАЛЬНУ ЧАСТИНИ СМТ. СХІДНИЦЯ

Мета роботи – оцінити величину похибки ортотрансформування аерознімків по висоті, отриманих з безпілотного літального апарату на гірську ділянку смт. Східниця за допомогою додаткової сітки точок ГНСС-знімання. Завдання роботи – проаналізувати різниці висот точок, отриманих за допомогою карти висот із БПЛА і даних ГНСС-знімання. Оцінити розходження реальних координат опорних точок з їх координатами на ортофотоплані. **Методика.** Запропоновано методику визначення реальної величини висотної похибки ортотрансформування аерознімків, отриманих із БПЛА на гірську місцевість. Створено локальний тестовий майданчик на горі в смт. Східниця розміром приблизно 70×60 метрів, шо входить у створене загальне аерознімання. Тут виконано додаткове ГНСС-знімання і створено мережу точок із координатами через кожен метр. Отриманий ортотрансформований знімок з картою висот за даними аерознімання всієї Східниці й результатами ГНСС-знімання через кожні 50 метрів відкрито в програмному забезпеченні ArcGIS. На аерознімок нанесено шар точок локальної ділянки і порівняно з координатими тих самих точок, отриманих із карти висот. **Результати.** Порівнюючи висотні показники 87 точок на схилі гори в смт. Східниця, отримані за допомогою ГНСС-знімання, з висотними показниками тих самих точок, взятих із карти висот, створеної за даними аерознімання з безпілотного літального апарата, визначено, що висотні показники точок не дуже відрізняються. Середня квадратична похибка становить 0,39 м. **Наукова новизна.** Запропоновано методику порівняння висотних показників точок місцевості, отриманих різними методами для визначення величини похибки ортотрансформування аерознімків, отриманих з БПЛА на гірську локальну ділянку смт. Східниця. **Практична значущість.** Отримані результати величини похибки ортотрансформування аерознімків, отриманих з безпілотних літальних апаратів на окрему гірську частину смт. Східниця, вказують на те, що ортотрансформування аерознімків окремих гірських територій з БПЛА є в зоні допуску.

Ключові слова: ортотрансформування, ортофотоплан, аерознімання, БПЛА; ГНСС-знімання, визначення величини похибки

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