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ESTIMATION ACCURACY OF ORTHOTRANSFORMATION OF SPACE IMAGES APPLYING SATELLITE PLEIADES-1 BY GNSS SURVEYING

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Aim. Perform an estimation of the accuracy of the orthotransformation of the satellite images obtained from the satellite Pleiades-1 on the territory of settlement Skhidnytsya (Ukraine). **Methods.** The method used in the experiment included photogrammetric and geodetic work. Geodetic work consisted of field measurements of coordinates of reference and control points using GNSS. The Erdas Imagine software package transforms a space image from the Pleiades-1 satellite from with RPC coefficients. Further, is applyied a layer of points on a transformed image obtained with GNSS revealed significant deviations of the image points from the real (especially in mountainous terrain). To reduce the deviations in the MathCAD software, a program has been created to calculate the RPC model formulas. Using this model the coordinates of the points of the picture and the coordinates of the points in the area, we obtain the refined coefficients for the given plot. These coefficients have been replaced with the RPC file. Transformation of the image after the updated file was carried out, resulting in a satisfactory result. **Results.** The results of the study of orthotransformation accuracy of space images of the village Shidnytsia (Ukraine) received applying satellite Pleiades-1 are considered in this article. Estimation accuracy has been done basing on coordinates of 165 points obtained from GNSS surveying. Projective mathematic model RPC have been determined analytically with the help of unknown coefficients. Based on these coefficients retransformation of image has been done, the average square error of coordinate displacement has been determined. **Scientific novelty**. It was determined during the research that the RPC coefficients that firms provide with space image are rather conditional because they are derived from global DEM. In order to refine the coefficients, the solution of the mathematical model was programmed. Using this data, you can edit a file with RPC-coefficients.**The practical significance.** The result of the experiment was a transformation of the image into the local territory of the village of Shednitsa. The transformed image allows to update a previously created tourist map at a scale of 1: 6000 on request of the village management or to create other thematic maps.

Key words: orthotransformation, Pleiades-1 estimation of coordinate accuracy, RPC-coefficients checkpoint.

Introduction

Nowadays, data of RS (remote sensing) are widely used in various branches of industries and science. Especially it is worth mentioning there is a significant expansion of types and methods of remote sensing of extremely spatial differences applying new satellites. The current regulatory framework of topographic and geodetic activities does not provide the possibility of using space technologies for topographic area mapping. Nevertheless, the rapid development of space surveying methods gives the possibility to apply them for topographic mapping. Data obtained by satellite are widely used for mapping, deciding applied tasks in various branches of science and technology and conducting geoinformation systems. The quality and quantity of material are increasing each year. Thus, applying this method gives new possibilities for development and application. The purpose of this study is to estimate the accuracy of orthotransformation of images received applying the satellite system Pleiades-1 (Grodecki J., Dial G.Block, 2003, Toutin T., 2004).

Aim

Perform an estimation of the accuracy of the orthotransformation of satellite images obtained from the satellite Pleiades-1 on the territory of settlement Skhidnytsya (Ukraine). Retransform image using refined data.

Methods

Estimation accuracy of orthotransformation of space image having received by applying satellite Pleiades-1

The input data of this study is orthotransformation space image obtained by using the satellite system Pleiades-1 (Fig. 1), the system of WGS-84 coordinates, and the catalogue of characteristic points of the village Shidnytsia in the system WGS-84 UTM 34N, which contains 165 points obtained with the help of GNSS surveying.

Geodetic checkpoints connection

Point coordination has taken place in real time (RTK) by dual-frequency GNSS receivers Trimble R7, Leica GX1230GG and South S82-2013. This mode allows receiving spatial coordinates of checkpoints directly without the necessity of further processing. Surveying has been done by network reference stations (CORS).

Fig. 1. The space image of the village Shidnytsia obtained from satellite Pleiades-1 in 2014

GeoTerrace belongs to the Geodesy Institute of Lviv Polytechnic National University. Reference stations SKOL, SAMB and STRY are located near the surveying object (at the distance 25 km, 34 km, and 36 km respectively) (Fig. 2). The estimation accuracy of set checkpoint coordinates has been 5 cm and its altitude position has been 7 cm.

The points chosen as checkpoints are such which can be decoded clearly at space images. The possibility of coordinating single corners of buildings, trees, etc. has been put off at once because they prevent satellite signal and make the result of measurement worse.

Clear contours in open areas are the best, for example, corners of fences, metal centers of trapdoors, and drainage elements of road marking. Another important condition of checkpoints is their situation on the Earth's surface. In extra cases, when there is no clear contour in certain surveying area it is allowed to use checkpoints located above the Earth's surface, but not higher than 50 cm.

Determining differences of point coordinates obtained by applying GNSS and points of apparatus orthotransformation images

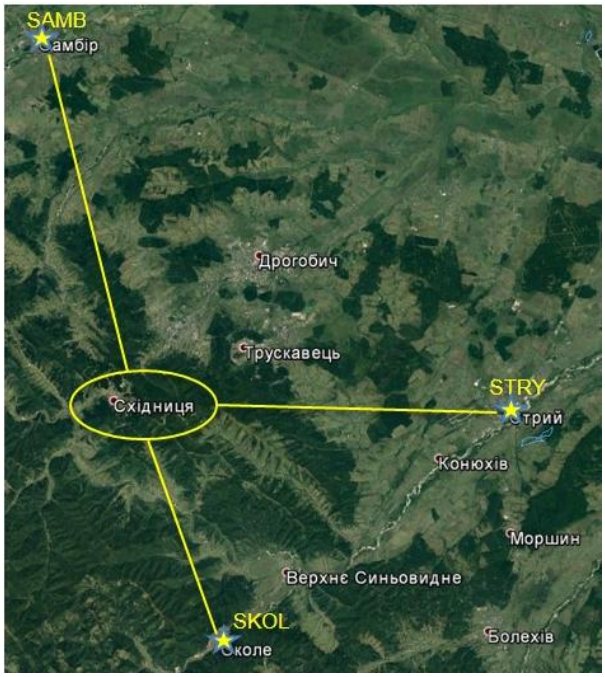
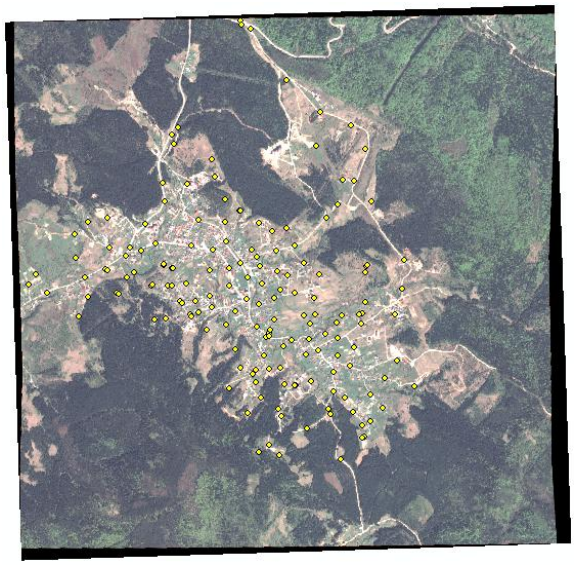


Fig. 2. Surveying network

Fig. 3. The process of checkpoints connection

Thus, all study has been performed using two programs: ArcGIS and Erdas Imagine, it has been necessary to prepare a catalogue of 165 points coordinates obtained by applying GNSS. They are necessary to fulfill these programs. For this purpose a catalogue of coordinates has been transformed out of the Excel-table form into dBase IV format, in order to read it in ArcMap format.

Using module ArcMap, the data of the points obtained by applying GNSS are set based on known coordinates of space orthotransformation image. Set points have been yellow (Fig. 4).



Attributes of koord_sh Events

OID	X	Y	Z
0	5455599,343	670401,106	583,93
1	5455606,085	670407,911	583,431
2	5455404,204	670291,216	600,881
3	5455413,625	670302,349	602,917
4	5455404,614	670445,127	612,327
5	5455409,002	670485,754	612,681
6	5455258,888	670558,921	607,051
7	5455244,564	670576,613	607,34
8	5455132,421	670649,816	616,714
9	5455121,235	670660,847	618,022
10	5455099,054	670421,46	607,12
11	5455092,13	670317,446	614,338
12	5455338,544	669966,492	597,979
13	5455327,683	669978,888	598,516
14	5455485,733	670063,581	560,585
15	5455531,012	670123,036	559,423
16	5455686,513	670045,896	563,602
17	5455727,317	670196,392	563,8
18	5454183,27	671505,092	650,568
19	5454257,417	671476,198	650,957
20	5454481,753	671530,672	646,547
21	5454473,338	671640,095	634,888
22	5454475,048	671629,862	635,314
23	5454509,49	671786,041	620,073
24	5454210,721	671962,801	627,519
25	5454072,833	671742,302	646,929
26	5453921,813	671390,368	695,585
27	5453825,596	671491,372	699,414

Record: 1 Show:

Fig. 4. Set points obtained using GNSS from space orthotransformation image

To determine the points location at the image separate shape-file has been conducted (Real_coords). The process of finding points at orthotransformation image is that points are marked manually according to their location based on GNSS-data. The results are recorded in shape-file Real_coords. The analysis of point coordinate differences is also done (Fig. 5).

The Add XY coordinates have been used in order to get a table of attributive data of coordinates of the image. After using it to attributive, extra columns are set – POINT_X and POINT_Y, where coordinates X and Y are set for each point at the image (Fig. 6).

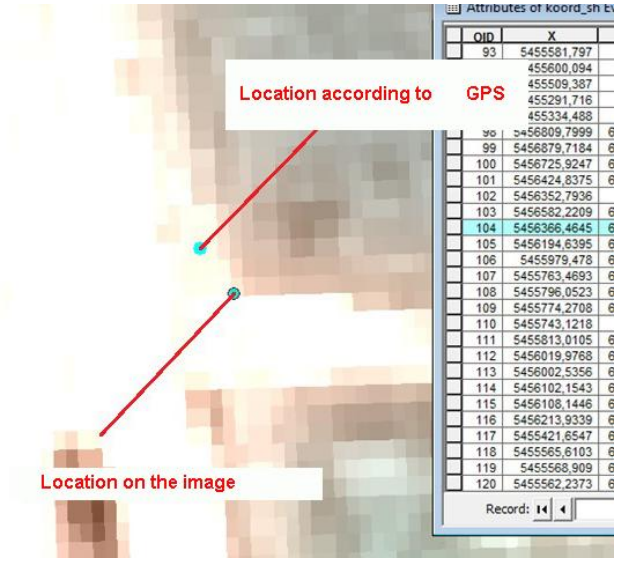
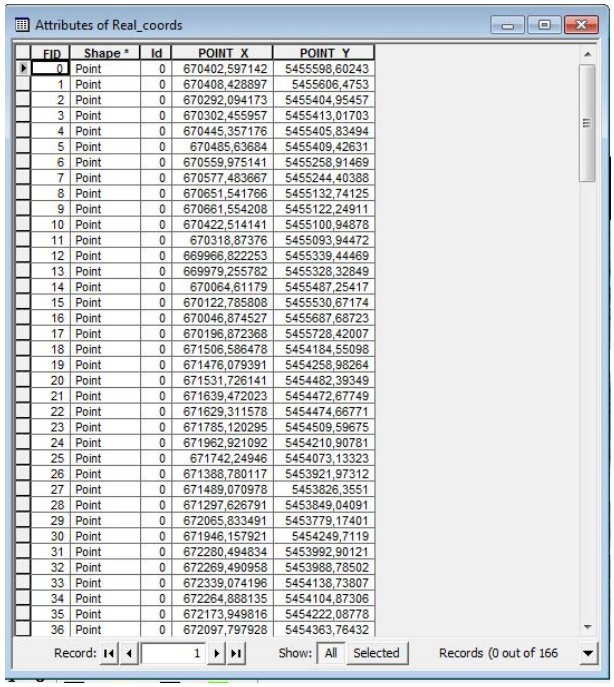


Fig. 5. The example of points difference measured using GNSS and received with the help of orthotransformation image



Attributes of Real_coords

FID	Shape *	Id	POINT_X	POINT_Y
0	Point	0	670402,597142	5455598,60243
1	Point	0	670408,428897	5455606,4753
2	Point	0	670292,094173	5455404,95457
3	Point	0	670302,455957	5455413,01703
4	Point	0	670445,357176	5455405,83494
5	Point	0	670485,63684	5455409,42631
6	Point	0	670559,975141	5455258,91469
7	Point	0	670577,483667	5455244,40388
8	Point	0	670651,541766	5455132,74125
9	Point	0	670661,554208	5455122,24911
10	Point	0	670422,514141	5455100,94878
11	Point	0	670318,87376	5455093,94472
12	Point	0	669966,822253	5455339,44469
13	Point	0	669979,255782	5455328,32849
14	Point	0	670064,61179	5455487,25417
15	Point	0	670122,785808	5455530,67174
16	Point	0	670046,874527	5455687,68723
17	Point	0	670196,872368	5455728,42007
18	Point	0	671506,586478	5454184,55098
19	Point	0	671476,079391	5454258,98264
20	Point	0	671531,726141	5454482,39349
21	Point	0	671639,472023	5454472,67749
22	Point	0	671629,311578	5454474,66771
23	Point	0	671785,120295	5454509,59675
24	Point	0	671962,921092	5454210,90781
25	Point	0	671742,24946	5454073,13323
26	Point	0	671388,780117	5453921,97312
27	Point	0	671489,070978	5453826,3551
28	Point	0	671297,626791	5453849,04091
29	Point	0	672065,833491	5453779,17401
30	Point	0	671946,157921	5454249,7119
31	Point	0	672280,494834	5453992,90121
32	Point	0	672269,490958	5453988,78502
33	Point	0	672339,074196	5454138,73807
34	Point	0	672264,888135	5454104,87306
35	Point	0	672173,949816	5454222,08778
36	Point	0	672097,797928	5454363,76432

Record: 1 Show: All Selected Records (0 out of 166

Fig. 6. Attributive table of point coordinates obtained using orthotransformation image

To calculate the distance between the point location at the image and the real location of them based on GNSS data, the formula 1 is applied and the error is calculated by the coordinates.

$$\Delta=\sqrt{(X_{im}-X_{GPS})^2+(Y_{im}-Y_{GPS})^2}, \quad (1)$$

where Δ is the distance between points; X_{im} is position of X coordinates at the image; X_{GPS} is a position of X coordinate based on GNSS data; Y_{im} is position of Y coordinate at the image; Y_{GPS} is position of Y coordinate based on GNSS data surveying (Table 1).

Summary Table 1 has been conducted based on the received results. Based on the result of differences graphic of vectors coordinates displacement (Fig. 7) has been build. The displacement vectors have small length (from 0 to 6 m) and the image is approximately 4×4 km in size. Thus, to make it clear vectors are set in another scale.

Having analyzed this graphic it is clear that the greatest index of points displacement are in the northern and southern parts of the image. These areas are hills or mountains. Thus, it can be considered that significant displacement of coordinates are due to incorrect determination of points' altitude with the help of satellite.

Based on 165 points and using formula 2 the average square error of point coordinates displacement obtained by using space images of their real location is calculated (Michele Bianconi et al, 2008; Blackett Shane Allan, 1996).

$$m=\sqrt{\frac{[v^2]}{n}} \quad (2)$$

$$[v^2]=854.71 \text{ m}$$

$$m=\sqrt{\frac{[854,71]}{165}}=2.28 \text{ m}$$

Thus, analyzing the result average square error of point coordinates displacement obtained from the transformed image and their real location it can be said that it is almost 5 times more than spatial defining images from this survey (0.5 meters) and it is approximately 5 pixels (2.28 m). The unknown coefficients $a_0 \dots a_6$, $b_1 \dots b_6$,

Table 1

Part of the summary table of point coordinates of real location and their set at the image; differences between them

Coordinates obtained from the GNSS		Coordinates obtained from the image		Δ
5455404.61	670445.12	5455405.83	670445.35	0.77183
5455409.00	670485.75	5455409.42	670485.63	0.09688
5455258.88	670558.92	5455258.91	670559.97	0.55596
5455244.56	670576.61	5455244.40	670577.48	0.39184
5455132.42	670649.81	5455132.74	670651.54	1.54041
5455121.23	670660.84	5455122.24	670661.55	0.76428
5455099.05	670421.46	5455100.94	670422.51	2.35070
5455092.13	670317.44	5455093.94	670318.87	2.66585
5455338.54	669966.49	5455339.44	669966.82	0.46015
5455327.68	669978.88	5455328.32	669979.25	0.27596
5455485.73	670063.58	5455487.25	670064.61	1.68824
5455531.03	670123.03	5455530.67	670122.78	0.08918
5455686.51	670045.89	5455687.68	670046.87	1.16816
5455727.31	670196.39	5455728.42	670196.87	0.72375
5454183.27	671505.09	5454184.55	671506.58	1.93718
5454257.41	671476.19	5454258.98	671476.07	1.23264
5454481.75	671530.67	5454482.39	671531.72	0.76072
……..	…….	…….	……	……..

$$c_0 \dots c_6 , \; d_1 \dots d_6$$

have been determined analytically by the projective transformation formula (3) in order to further clarifying it (Tao Vincent C. and Yong Hu. 2001; Xutong Niu et al., 2004; Lutes J., 2004; Shirokova T. and Chermoshentsev A., 2011)

$$x = \frac{a_0+a_1X+a_2Y+a_3Z+a_4X^2+a_5XY+a_6XZ}{1+b_1X+b_2Y+b_3Z+b_4X^2+b_5XY+b_6XZ} , \quad (3)$$

$$y = \frac{c_0 + c_1X + c_2Y + c_3Z + c_4X^2 + c_5XY + c_6XZ}{1 + d_1X + d_2Y + d_3Z + d_4X^2 + d_5XY + d_6XZ} .$$

Based on these calculations coefficients are set:

a_0=0.013623	b_1=-0.005911	c_0=1.06726e-06	d_1=-0.0034001
a_1=-0.083331	b_2=-0.006115	c_1=-5.68589e-05	d_2=0.006479
a_2=-0.912323	b_3=-1.05886e-06	c_2=-3.89474e-05	d_3=1.905423e-05
a_3=0.004122	b_4=2.10743e-06	c_3=1.22434e-05	d_4=4.33446e-06
a_4=-0.004428	b_5=-7.32964e-05	c_4=5.578301e-06	d_5=2.52561e-06
a_5=0.000155	b_6=-6.29642e-05	c_5=1.25702e-06	d_6=-6.96355e-07
a_6=6.81081e-05		c_6=-5.52371e-08	

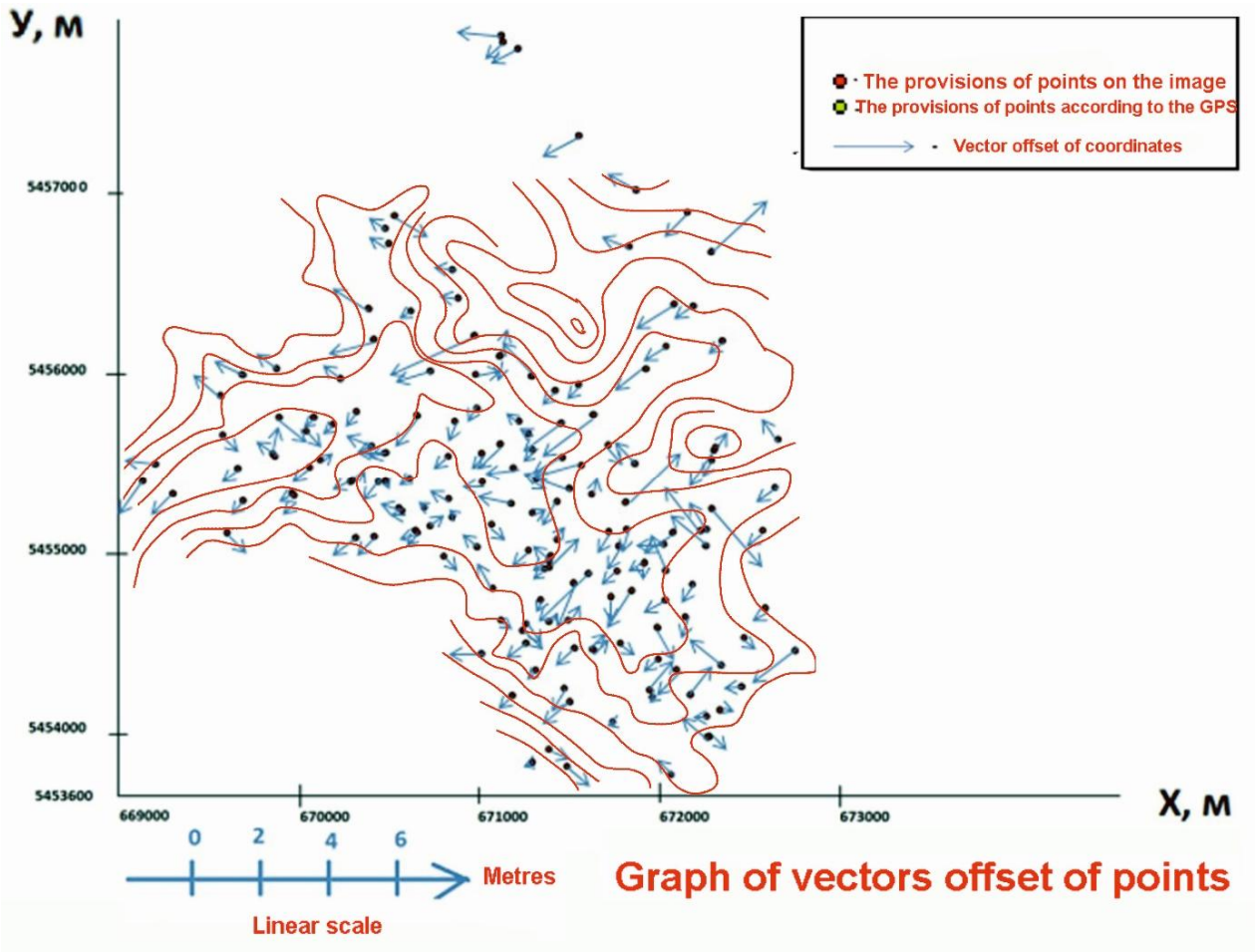


Fig. 7. Graphic of vectors of point coordinates displacement

Accuracy retransformation of space image and calculation of the output of average square error

Space images from the satellite Pleiades-1 in jpeg2000 kit format and a file of received apparatus RPC coefficients in expansion xml format are included to the same complex. For this image, this file is called RPC_PHR1B_PMS_ 201404280954030 _SEN_1332795101-001.xml (Fig. 8).

Having corrected this file in accordance with analytically calculated RPC coefficients again the actions described in paragraph 2.2 have been done sequentially, and the orthotransformation of the image has been conducted (Voronin A., 2009; Hnatushenko V., 2009; Pilicheva M., 2009).

Having applied the refound 165 points at retransformed space image it has been determined that the error of point coordinates from the image and those from applying GNSS is from 0 to 1.1 meters. The example of the differences of specified point coordinates has been shown at Fig. 9.

```
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  <Metadata_Identification>
    <METADATA_FORMAT version="2.0">DIMAP</METADATA_FORMAT>
    <METADATA_PROFILE>PHR_SENSOR</METADATA_PROFILE>
    <METADATA_SUBPROFILE>RPC</METADATA_SUBPROFILE>
    <METADATA_LANGUAGE>en</METADATA_LANGUAGE>
  </Metadata_Identification>
  <Rational_Function_Model>
    <Resource_Reference>
      <RESOURCE_TITLE version="2.1">NITF</RESOURCE_TITLE>
      <RESOURCE_ID>RPC00B</RESOURCE_ID>
    </Resource_Reference>
    <Global_RFM>
      <Direct_Model>
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        <SAMP_NUM_COEFF_2>0.987553039841472</SAMP_NUM_COEFF_2>
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8>
        <SAMP NUM COEFF 9>-0.000148618006716411
```

Fig. 8. The example of code setting file of RPC coefficients obtained simultaneously with the image

Recalculated average square error according to the accurate data is 0.69 m:

$$m = \sqrt{\frac{[78{,}08]}{165}} = 0{,}69 \text{ m}$$

The results obtained out of image transformation coefficients showed that the average square error of point coordinates displacement at the image and their real location has decreased almost 4 times and is approximately the value of spatial differentiation of space images.

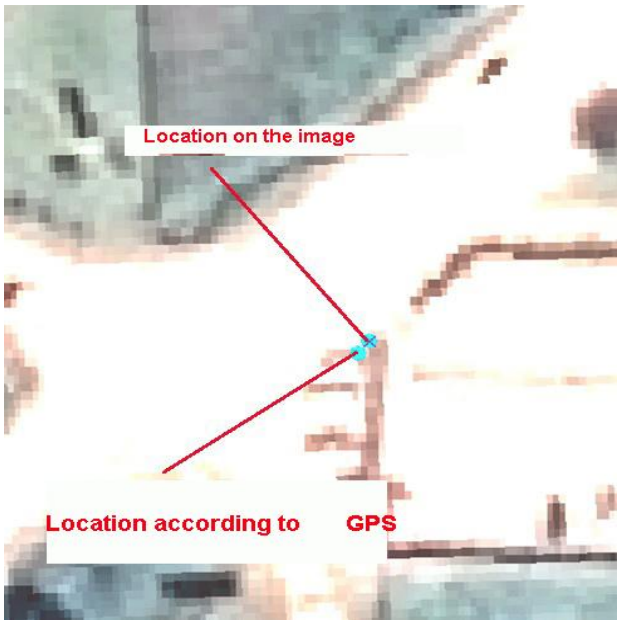

Fig. 9. The example of point displacement measured by applying GNSS and those from the retransformation image

Conclusions

Having learned accuracy of orthotransformation of space images from satellite Pleiades-1 of the village Shidnytsia (Ukraine) it can be summarized that:

1. Accuracy of orthotransformation of space image obtained on commercial basis has been quite significant. The average square error index of 165 points with coordinates obtained from the real image of the location determined by GNSS measurements has exceeded 5 times the spatial difference of the image CN and ICA and is 2.28 meters.

2. Based on received indexes of coordinate points displacement graphic of vectors coordinate points displacement has been formed. The analysis showed that the largest coordinate points displacement is located in the mountainous area. Thus, it can be considered that determination of altitudes by satellite apparatus is quite approximate.

3. The unknown coefficients have been based on actual points of altitude obtained with the help

of GNSS and are determined using rational polynomials formulas.

4. Using the received coefficients, the accurate orthotransformation of space image has been done and the average square error has been calculated based on those 165 points. After clarifying orthotransformation image the average square error index has been improved significantly (about 4 times) and is 0.68 m, which is approximately the index of special image difference.

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ОЦІНЮВАННЯ ТОЧНОСТІ АПАРАТНОГО ОРТОТРАНСФОРМУВАННЯ КОСМІЧНОГО ЗНІМКА, ОТРИМАНОГО ІЗ СУПУТНИКА PLEIADES-1 ЗА ДОПОМОГОЮ ГНСС-ЗНІМАННЯ

Мета. Виконати оцінювання точності ортотрансформування космічного знімка, отриманого з супутника Pleiades-1 на територію смт. Східниця (Україна). **Методика.** Метод, який використано в експерименті, включав фотограмметричні та геодезичні роботи. Геодезична робота складалася з польових вимірювань координат опорних та контрольних точок з використанням GNSS. Програмний пакет Erdas Imagine трансформує космічне зображення з супутника Pleiades-1 за RPC-коефіцієнтами. Застосування на трансформованому зображенні шару точок, отриманих за допомогою GNSS, виявило значні відхилення координат точок зображення від реальних (особливо в гірській місцевості). Для зменшення відхилень у програмному забезпеченні MathCAD створено програму для розрахунку формул RPC-моделі. Використовуючи в цій моделі координати точок зображення і координати точок місцевості, отримано уточнені коефіцієнти для цієї ділянки. Ці коефіцієнти замінено у файлі RPC. Була виконана трансформація зображення після оновлення файлу, що призвело до задовільного результату. **Результати.** У статті розглянуто результати дослідження точності ортотрансформації космічних зображень села Східниця (Україна), отриманих із застосуванням супутника Pleiades-1. Точність оцінювання проведена на основі

координат 165 точок, отриманих під час знімання GNSS. Проективні математичні моделі RPC визначають аналітично за допомогою невідомих коефіцієнтів. На основі цих коефіцієнтів виконано перетрансформацію зображення, визначено середню квадратичну похибку зміщення координат. **Наукова новизна**. Під час дослідження визначено, що коефіцієнти RPC, які фірми надають з космічним зображенням, досить умовні, оскільки вони походять від глобальної ЦМР. Для уточнення коефіцієнтів запрограмовано розв'язок математичної моделі. Використовуючи ці дані, можна редагувати файл з RPC-коефіцієнтами. **Практичне значення**. Результатом експерименту стало трансформоване зображення на територію села Східниця. Перетворене зображення дасть змогу оновлювати раніше створену туристичну карту в масштабі 1: 6000 на прохання сільського управління або створювати інші тематичні карти.

Ключові слова: ортотрансформація, оцінювання точності координат Pleiades-1, RPC-коефіцієнти.

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