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Creating 3D Surface Models Using the Resurs-P Spacecraft Images

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Abstract. At the present time the Russian Earth remote sensing spacecraft group includes two spacecraft of the Resurs-P type that allow stereo survey of the Earth surface to be performed on one orbit circuit. The Geoton sensor images (panchromatic band with 1-meter resolution) were used to create the models. These models were created automatically by means of the digital photogrammetric station PHOTOMOD. The article contains the information about 3D surface mod-els made from stereo pairs with different convergence angles for the same territory. It is noted that these models are compared with each other from the accuracy and completeness of objects' reflection. The purpose of the comparison is to determine the optimal parameters for the Earth surface stereo survey.

Keywords: Resurs-P, stereo survey, stereo pair, digital surface model

Nowadays two spacecraft of the Resurs-P type (No. 1 was put into orbit on June 25, 2013; No. 2 was put into orbit on December 26, 2014) are being operated in the orbit. They are intended for maps updating, ensuring economic activity of various federal, regional, municipal departments, and other consumers, and for obtaining information in the field of control and environmental protection.

The target-oriented equipment:

- the optical-electronic GEOTON-L1 complex with the system for reception and transmission of information (SRTI) SANGUR-1U (Resurs-P No. 1, Resurs-P No. 2);
- the hyperspectral equipment – HSE (Resurs-P No. 1, Resurs-P No. 2);
- a complex of the wide-range multispectral surveying equipment (WMSE) of high (HR) and average resolution (AR): WMSE-HR and WMSE-AR (Resurs-P No. 1, Resurs-P No. 2).

The scientific equipment:

- a complex of research of galactic beams of ultra-high energies – Nucleon (Resurs-P No. 2).

Moreover, the onboard AIS receiver designed for radio signals receiving from sea vessels and their automatic identification is installed on board the Resurs-P No. 2 spacecraft.

Table 1. Basic characteristics of the GEOTON-L1 equipment

Characteristics name	Value
Focal distance, mm	4000
Entrance pupil diameter, mm	500
Relative hole	1:8
Field angle, °	5°18′
Photosensitive element size, μm panchromatic spectral	6x6 18x18
Pixel projection onto the Earth surface, m: in panchromatic band in narrow spectral bands	1.0 3.0–4.0
Swath width, km	38
Spectral bands, μm:	
panchromatic	0.62–0.79
blue	0.48–0.53
green	0.54–0.59
red	0.62–0.68
red 2	0.66–0.69
near red	0.70–0.75
near infrared 1	0.72–0.80
near infrared 2	0.81–0.88
Number of simultaneously used spectral bands	1–5
Linear coding bitness of videodata, bit/pixel	10

Table 2. Basic characteristics of the WMSE complex

Characteristics name	Characteristics value	
	WMSE-AR	WMSE-HR
Optical system: focal distance, mm relative hole field angle, °	 40 1:4 54°30′	 200 1:3 11°70′
Swath band, km	441.7	97.2
Pixel projection onto the Earth surface, m: in panchromatic band in narrow spectral bands	 59 118	 12 23.8

Spectral bands, µm:	
panchromatic	0.43–0.7
blue	0.43–0.51
green	0.51–0.58
red	0.60–0.70
IR 1	0.7–0.9
IR 2	0.8–0.9
Photosensitive element size, µm:	
panchromatic	5x5
spectral	10x10
Linear coding bitness of videodata, bit/pixel	12

Table 3. Basic characteristics of the hyperspectral equipment

Characteristics name	Value
Swath, km	30
Pixel projection onto the Earth surface, m	25–30
Spectral bands, µm	0.4–1.1
Channels quantity	not less than 96
Spectral resolution, nm	5–10

Table 4. Orbit parameters

Characteristics name	Value
Type	near-circular sun-synchronous
Height, km	470–480
Inclination, °	97.28
Surveillance periodicity, day	no more than 3

Survey modes

A route survey. Survey in the route mode can be carried out both with a constant value of heel and pitching angles (see Fig. 1) and with the set azimuth (Fig. 2). A spacecraft deviation on a heel and pitching from a nadir is possible up to ±45 °, on yawing is up uto ±60 °. Duration of routes is from 2 to 300 sec.

Route survey

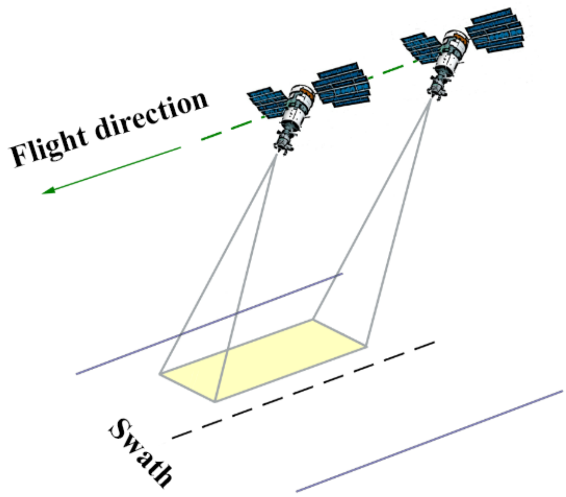

Fig. 1. Survey with a constant heel and pitching

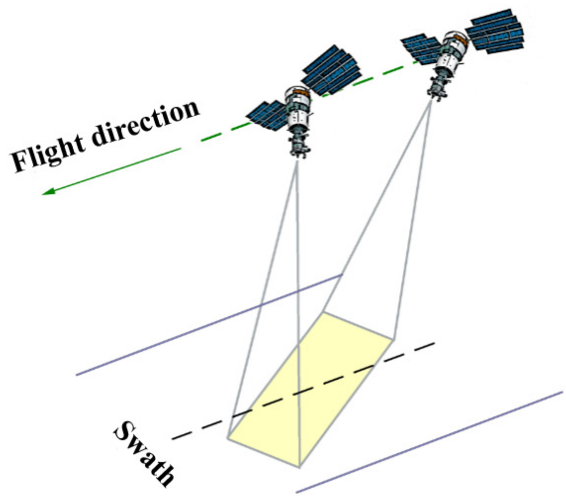

Fig. 2. Survey with the set azimuth

Stereosurvey. Stereosurvey is a receiving a stereopair[1] of images in the photographic way. Stereosurvey is carried out on one circuit with a device deviation on pitching. A length of routes is up to 115 km.

1 A stereopair is a combination of two images of the same object received from two different surveying points.

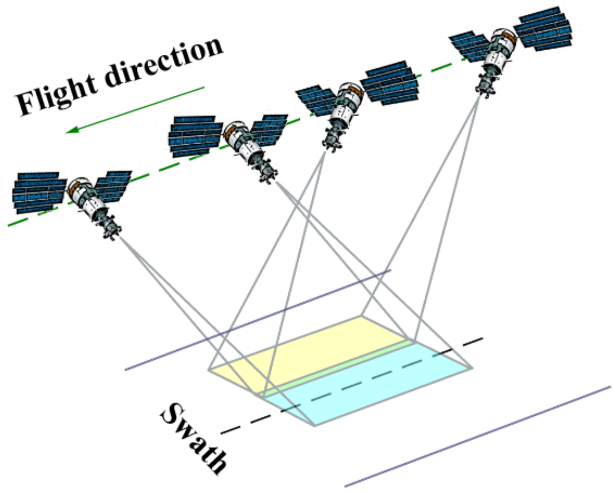

Fig. 3. Aerial survey

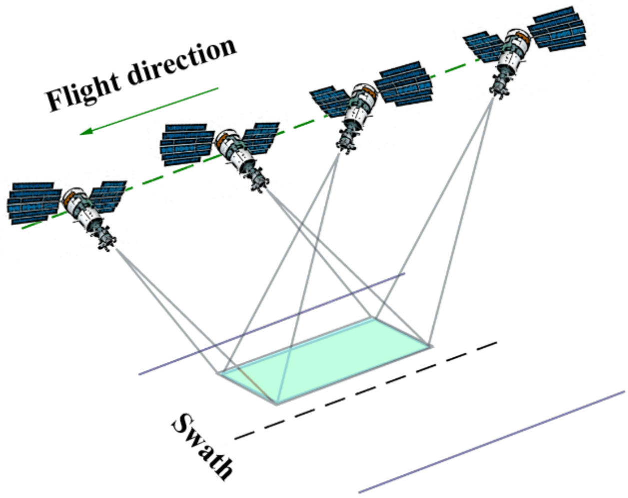

Fig. 4. Stereosurvey

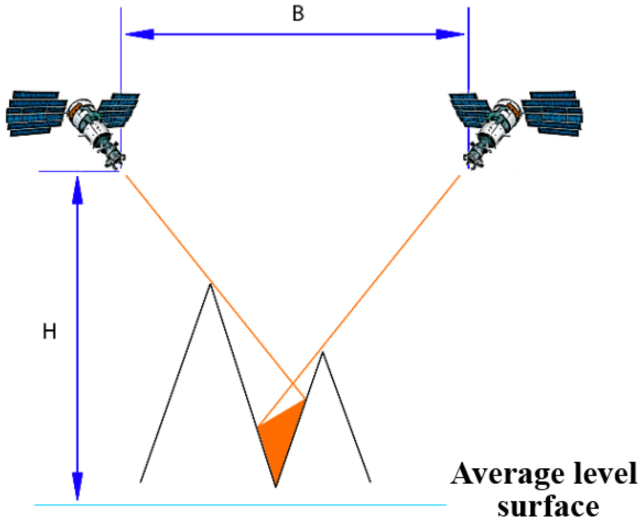

Fig. 5. A bigger *B/H* ratio

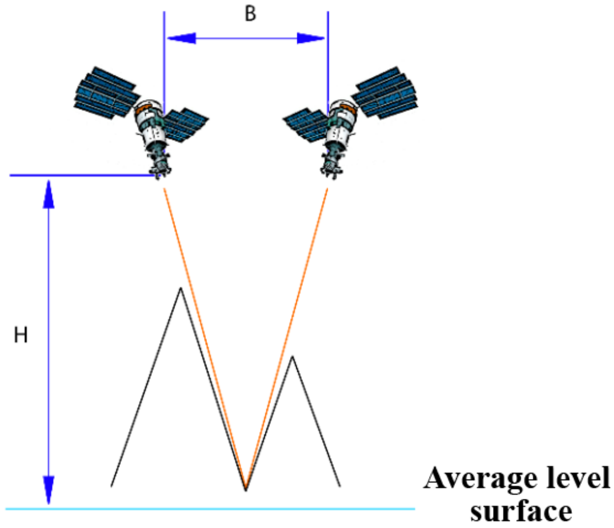

Fig. 6. A smaller *B/H* ratio

Creating a 3D model of the area

The materials of the stereosurvey became the basic data for creation of three-dimensional (3D) models of the area.

The key characteristics of the stereopair is the ratio of photography basis[2] to photography height – *B/H*.

At values of *B/H* ratio close to 1, a convergent angle[3] is about 54°. If stereosurvey is carried out with equal deviations on pitching, then deviation angles in that case are about 27°. Advantages of such stereosurvey parameters are the following: a big convergent angle allows one to increase the accuracy of measurements on a stereopair; a big area of a stereopair. Disadvantages: shadow zones on mountainous areas and areas with high-floor buildings; to create an orthophotomap it is necessary to carry out additional survey with small deviation angles from a nadir or use stereopair images with deviation from a nadir more than 20°.

In the world practice when stereosurvey is on one circuit (with deviations on pitching), the *B/H* ratio is chosen depending on a height difference in the territory under surveying. Therefore, optimum *B/H* ratios are values about 0.5. For mountainous areas, this ratio is reduced, and the ratio is increased for flat ones. Thus, convergent angles vary from 30° to 45°. To create a orthophotomap, stereosurvey can be carried out with different deviation angles of an optical axis from a nadir on pitching (for example, +20° and –10°), so to use a picture with a smaller deviation angle from a nadir for orthotransformation.

2 Photography basis is the distance between two neighbour photography points.

3 A convergent angle of the stereopair is the angle, which is formed by the crossed projecting beams of the stereopair images in the basic planes for the points of the same name.

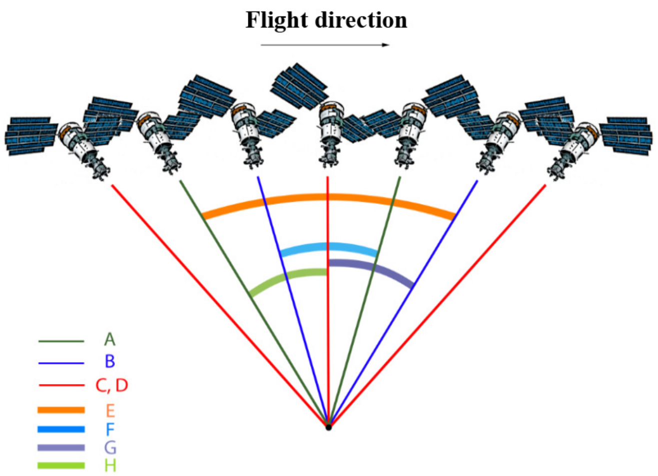

Fig. 7. Formed stereopairs

Table 5. Formed stereopairs parameters

Stereopair	Deviation angle from a nadir, °		Convergent angle, °
	Image No. 1	Image No. 2	
A	32.5	12.0	44.2
B	12.9	36.5	46.3
Triplet			
C	47.2	2.5	46.6
D	2.5	44.1	44.4
Additional stereopairs			
E	32.5	36.5	68.4
F	12.9	12.0	22.7
G	2.5	36.5	37.3
H	32.5	2.5	32.5

For creation of 3D models of the district, stereosurvey with the Resurs-P No. 1 spacecraft with the GEOTON-L1 equipment in the panchromatic range on a test area with various corners of deviations on pitching has been performed.

By results of this survey, four main stereopairs have been created (based on the criterion of survey on one circuit – *A, B, C,* and *D*) and four additional (are picked up for a convergent angle). Eight stereopairs for one territory, but with different convergent angles and ratios of *B/H* have been made in the result. The materials of 1A processing level have been used for photogrammetric processing.

As Fig. 7 and Table 5 show, there are similar stereopairs in the parameters: *A* and *B, C* and *D, G* and *H*. The pictures forming them have deviation corners, similar in size, from a nadir on pitching.

Photogrammetric processing is executed using PHOTOMOD. While processing, a block from seven pictures has been formed. Seven basic and 76 control points are used for performance of block equalizing and specification of external orientation of pictures (see Fig. 8).

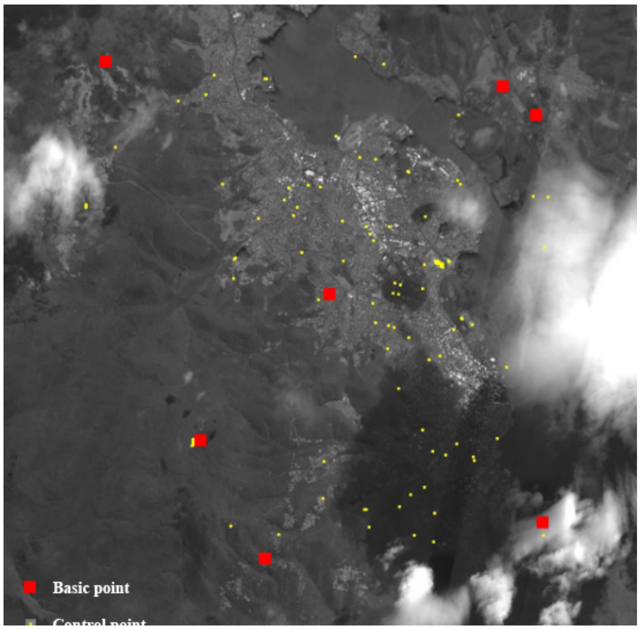

Fig. 8. A disposition scheme of basic and control points

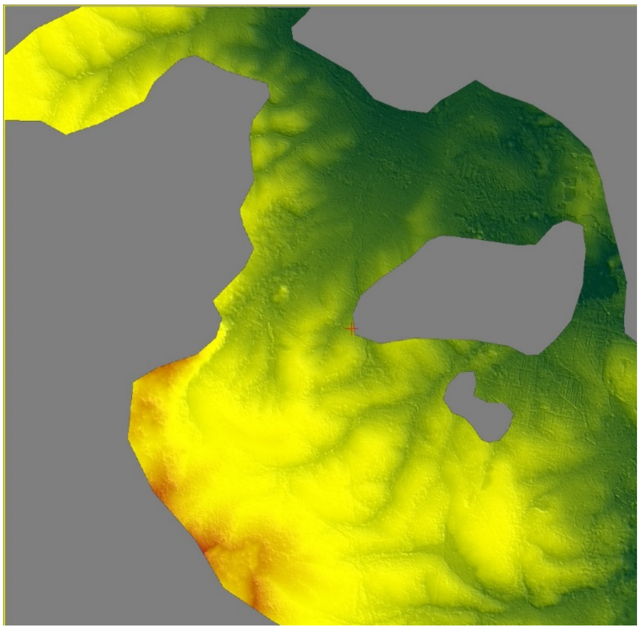

Fig. 9. A fragment of a digital area model No. 5

After adjustment, building of five digital area models is executed (further – DAM). Four DAM are constructed on stereopairs with the smallest errors for height when adjusting (are allocated green in Table 6). One additional DAM (see Fig. 9) is made using a new algorithm of the photogrammetric station PHOTOMOD for creation of dense DAM (employing repeated overlappings) with use of all seven pictures.

Table 6. Block adjustment results from eight stereopairs

Stereopair, No.	Convergent angle, °	Amount of basic points	Amount of control points	Maximum error on basic points in the plan, m	Maximum error on basic points for height, m	Standard deviation on basic points in the plan, m	Standard deviation on basic points for height, m	Maximum error on control points in the plan, m	Maximum error on control points for height, m	Standard deviation on control points in the plan, m	Standard deviation on control points for height, m
A	44.2	4	53	0.71	1.33	0.48	0.83	4.39	6.33	1.88	2.64
B	46.3	5	65	3.10	9.06	2.38	7.20	3.64	10.73	2.24	6.69
C	46.6	4	43	1.15	2.65	0.70	1.50	3.35	5.64	1.92	3.05
D	44.4	4	43	1.13	2.84	0.70	1.68	3.32	6.17	2.00	3.61
F	22.7	3	55	0.84	0.87	0.55	0.64	3.60	10.38	1.58	4.68
E	68.4	5	58	4.02	5.74	3.20	4.46	4.93	7.94	3.23	4.49
G	37.3	5	58	1.34	11.17	1.03	7.69	3.16	13.94	1.79	9.37
H	32.6	4	52	1.16	2.09	0.72	1.20	3.40	5.96	1.78	3.26

Table 7. Estimation of the accuracy of the created digital area models

Stereopair, No.	Amount of control points	Maximum error, m	Standard deviation, m
A	40	5.26	2.00
C	23	6.24	2.76
D	29	8.95	3.54
H	23	5.66	3.65
No. 5	49	12.17	6.13

Conclusion

As Tables 6 and 7 show, the stereopairs with convergent angles about 45° (the *B/H* ratio is about 0.8) and about 33° (the *B/H* ratio is about 0.5) were used for creation of DAM. At the same time, their precision characteristics are comparable. In this situation, the most preferable is a stereopair *H*, as it consists of pictures, one of which is almost not rejected from a nadir (2.5°). It will allow an orthophotomap with a minimum of distortions to be constructed.

In addition, it is worth paying attention to the stereopairs *B* and *G*. These stereopairs have surveys, similar in parameters, respectively, the stereopairs *A* and *H*. However, the orientation accuracy of the stereopairs *B* and *G* is almost twice worse, than that of the stereopairs *A* and *H*. Moreover, the stereopairs *F* and *E* have the maximum errors for height on control points more than seven meters. The stereopairs *B*, *F*, *E,* and *G* are united by presence in them of at least one picture from a stereopair *B*. The stereopairs *A*, *C*, *D,* and *H* do not have pictures from a stereopair *B*. The geometry of pictures of a stereopair *B* can serve as the reason of such result.

The following factors can serve as the main reasons for bad geometry of pictures of a stereopair *B*: spacecraft evolutions while surveying, deviation angles from a nadir, height difference on districts, and overcast. Deviation angles of pictures from a nadir at a stereopair *B* are comparable with deviation angles of pictures from a nadir of a stereopair *A*. However, the results of orientation of a stereopair *A* are significantly better. It means that spacecraft deviation angles from a nadir while surveying on geometry of a picture did not influence greatly, as well as a height difference on districts (the territory for surveying was the same one). The third picture of a triplet (the second picture of a stereopair *D*) was surveyed in conditions similar to conditions of surveying of the second picture of a stereopair *B*, even with a greater deviation angle on pitching. Though, the orientation accuracy of a stereopair *D*, in some parameters, is more than twice better than the orientation accuracy of a stereopair *B*. It confirms the assumption of a low influence on geometry of deviation angles of the spacecraft while surveying and a height difference of the district under surveying.

Stereosurvey was carried out in different days under different meteoconditions. Overcast is present in all seven pictures. In this case, various nature of overcast in days of survey could also become an important factor, which has influenced geometry of pictures of a stereopair *B*. Confirmation or a denial of this assumption requires carrying out a number of additional research and tests, as in this situation there can be additional factors influencing geometry of pictures.