MAPPING WITH THE USE OF RUSSIAN SPACE HIGH RESOLUTION IMAGES

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ABSTRACT:

The space mapping system developed and being used in Russia is the only one space tool in the world specially intended for mapping.

Satellite cartographic system combined of topographic camera TK-350 and high resolution camera KVR-1000 integrated with on-board equipment for external orientation elements determination is designed to provide large scale topographic and digital maps. On-board equipment includes two star cameras, laser altimeter, navigation sensors and synchronizing devices. In order to obtain joint operation and to provide required accuracy all the hardware is integrated into the common system based on constructional, accuracy and timing parameters.

The use of TK-350 and KVR-1000 images allows to produce topographic maps of 1:50000 scale, as well as digital and thematic maps of any region without ground control information. Images made by KVR-1000 camera allow to produce photoplans and orthophotoplans of 1:10000 scale. It is also possible to increase the accuracy using ground control points, for example GPS.

There is considered the technology of production of topographic and digital maps including the follow processing steps:

- production of frame and densification stereophotogrammetric networks allowing to obtain control points over any territory;
- stereophotogrammetric processing of TK-350 topographic images in order to obtain contour lines or Digital Elevation Models;
- production of orthophotoplans using KVR-1000 high resolution panoramic images;
- interpretation of high resolution satellite images;
- production of thematic maps of various types using TK-350 and KVR-1000 images.

Taking into account that modern technologies of mapping and GIS databases generation are mainly oriented to digital image processing, the TK-350 and KVR-1000 photo films can be digitised with given aperture and processed in digital form.

One of the main features of digital high resolution images is a large volume of information (one KVR-1000 image 18õ18 cm in format occupies about 600 Mbytes in digital form). Therefore, for on-line storing of the data sets SOVINFORMSPUTNIK uses faultless Intel-based servers with the volume of disk space more than 170 Gbytes. Processing of digital images of volume larger than 500 Mbytes each is performed on workstations Silicon Graphics Indigo2 High Impact (under IRIX 6.2) and Pentium Pro (under Windows NT and Windows 95) using such software as ER Mapper, ERDAS Imagine, Photoshop.

Due to the fact that topographic TK-350 images and panoramic KVR-1000 images have specific geometric parameters, existing software products appeared to be unusable for production of DEM, orthorectified and geocoded images using these data. Therefore, SOVINFORMSPUTNIK developed a software product ORTHOSPACE intended for these purposes.

Thus, at present there are all preconditions for acquisition of Russian high resolution satellite images and their processing with the purpose of production of topographic and digital maps as well as GIS products.

The materials of the space survey are widely used all, over the world for the mapping purposes and GIS systems. The volume of the mapping and GIS products constantly increases as the analysis of the world market shows. Each year more and more new applications of the space survey data appear.

For the space survey for the mapping purposes the state and commercial organisations of the developed countries develop more new space systems, which provide high resolution and accuracy of the received data. In Russia the existing space systems start to be used wider and wider and new systems are being developed.

For the solution of the mapping tasks the space images are to have the best resolution in order to be used as a basis for the production of large-scale maps. From the other side these images are to have large coverage in order to provide the effective mapping of large territories. One of the ways in order to overcome this contradiction is the implementation of the space survey by the two types of cameras: short focus and long focus ones. Respectively the space images are worth classifying into the topographic and deciphering ones. The realisation of this way is carried out at the development of the space mapping system " Kometa" (Russia) the description of the survey equipment of which is given by the author in [1]. The space mapping system " Kometa" which includes the topographic camera TK-350, the deciphering camera KVR-1000 and the on-board equipment for the definition of the external orientation elements of images realises the classical principle of the plane stereoscopic survey of the terrain by the subsequent overlapping routes. Such method allows providing the continuous survey of large areas at each launch of the spacecraft (SC).

At present the digital techniques of the data processing found their rapid development all over the world. As a result the space systems which allow to receive the data in the digital form such as SPOT (France), IRS (India), IKONOS (USA) and others began to appear. These systems provide the acquisition of the terrain images with the resolution from 1 to 10 m and provide the stereoscopic coverage by the method of the conversion (êîíâåðãåíòíîé) survey. The advantage of our systems is the high resolution and the high accuracy of the navigational parameters that allows us developing full value maps in of a very wide range of scale from 1:25000 and smaller. However the indicated systems do not carry out the phase by phase contigineous coverage of large areas, the stereo pairs are formed as the result of the acquisition from various routes or the orbit round, they do not have the stable value of the ratio of the basis Â to the acquisition height Í, the scale of the image is not the same with respect to the field of the frame.

Thus especially taking into account the big amount of the already acquired archive data the use of the Russian space high-resolution images acquired by ÊÍÑ " Kometa" is considered as a rather perspective for the commercial use in the mapping purposes. Proceeding from the fact that the modern mapping technologies are oriented mainly towards the digital processing the analogue photos of TK-350 and KVR-1000 can be digitised with the pre-set discrete and processed in the digital form.

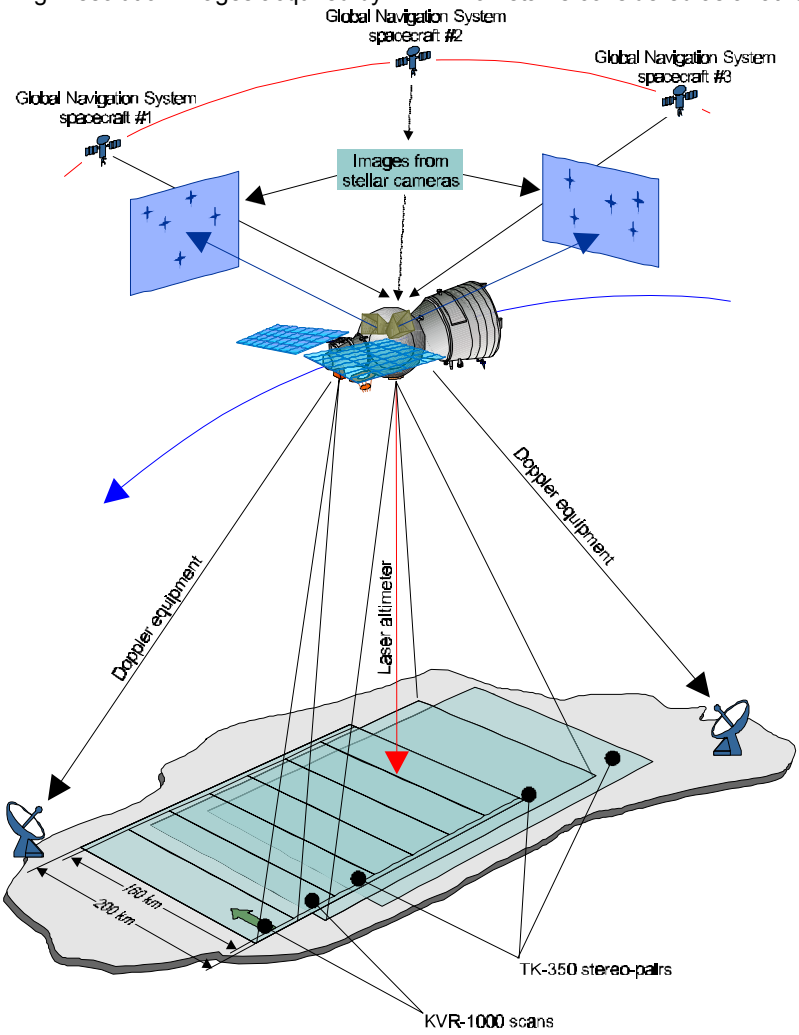

Fig.1

In the present article the principles of the design of the space system " Kometa" and the mapping capacity of the processing of image acquired by the system are considered.

Principles of the design of the mapping space system "Kometa".

The space mapping system " Kometa" includes the topographic camera TK-350, the panoramic camera KVR-1000, two star photo cameras, laser altimeter and synchronisation devices. In order to provide the joint work and the obtaining of the required accuracy all the equipment is grouped into one single system on the basis of the design, time and accuracy parameters. The scheme of the acquisition of the data is shown in Fig. 1.

General characteristics of TK-350 and KVR-1000 cameras taken from article [1] are given in Table 1.

Camera	TK-350	KVR-1000
• Focal length	350 mm;	1000 mm;
• Frame	300 x 450 mm;	180 x 720 mm;
• Relative aperture format	1 : 5.6	1 : 5
• Optical power	80 lines/mm in center 35 lines/mm on the edge	60 lines/mm in center
• Distortion	20 mkm - maximum 2.5 mkm - RMS of calibration	16 mkm - maximum
• Light filter	OS-14, orange	OS-14, orange
• Calibration crosses	with 10 mm step	-
• Imagery shift compensation	available	available
• Longitudinal overlap	60% or 80%	6% - 12%

Table 1.

The topographic camera TK-350 allows accomplishing the stereo survey of the terrain with the coverage swath of 200 km at the length of the routes up to 2000 km. At this the contigeneous coverage of the terrain by images with the longitudinal overlapping 60% or 80% and the traverse overlapping between the routes from 10% to 30% are provided. The pre-assigned overlapping between the routes is provided by the selection of the orbit with its subsequent correction to achieve the required orbit rotation period and the interval between the rotations. At the longitudinal overlapping of 80% the stereo photographic image processing of images with the overlapping of 20%, 40%, 60% and 80% is possible. That allows to increase the accuracy of the definition of the heights of the terrain points which depend on the ratio Â/Í (the imaging basis to the height). Thus for TK-350 images this ratio is as follows:

At ð ô =20%	Â/Í=1,04;
at ð ô =40%	Â/Í=0,77
at ð ô =60%	Â/Í=0,52
at ð ô =80%	Â/Í=0,26

As it can be seen the maximum Â/Í ratio will be at ð ô=20%, i.e. the stereo pairs will be formed by the images 1-5, 2-6, 3-7 and so on. For the definition of the external orientation elements of the topographic images the " Kometa" on-board equipment includes:

- Two star cameras;
- Laser altimeter;
- Navigational Doppler equipment;
- Synchronisation system.

Two star photo cameras provide the imaging of the star sky at the moment of the photographing of the terrain by the topographic photo equipment. The star cameras have the focus distance of 2000 mm, the format of the frame of 12×18 sm. And provide the imaging of stars up to the 6th star magnitude. The star cameras structurally with the help of the special frame are rigidly connected with each other and the topographic camera. The structural spatial angles between these cameras are calibrated with high accuracy. By the photo images of the star sky with the use of the structural angles as a result of the measurement and calculation processing the angle elements of the external orientation of the topographic images are determined.

The laser altimeter is designed for the measurement of ranges from the spacecraft to the points of the reflection of the signal from the Earth surface at the moment of the exposure of the topographic images. The indications of the laser altimeter are used to define the altitude of the imaging with RHS ¡=2 m. Such high accuracy is achieved at the cost of the small dispersion of the laser beam (of about 20 m in the terrain) and due to the precise registration of the reflection point. For the detection of the reflection point in the topographic image the special device which includes the triple prisma and the co-ordination photo registration unit of the reflection point is used. The laser altimeter works in two modes. In the first mode it is included together with the topographic photo camera for the definition of the imaging points height and in the second mode it is included to measure the ranges up to the water surfaces of open seas and oceans for the definition of the orbit altitudes.

The on-board Doppler equipment is used for the measurement of the radial velocity of the flight of the spacecraft and the synchronisation system provides the synchronisation of the work of all the measurement equipment and the referencing of the fixed time moments to the single scale with the accuracy of 10^{-12} s. The Doppler measurements of the spacecraft radial velocity, the measurement of the flight altitude by the laser altimeter and the time of the time of the switch of all the equipment is used to define the linear elements of the external orientation of the topographic images y the ballistic way of the solution of the edge task.

Thus the TK-350 topographic camera allows to realise the principle the plane stereoscopic survey and together with the measurement information allows to provide the development of the stereo photogrammetry networks of the creation of the plane and height basis and the definition of the terrain relief for topographic maps and DEM for any territory without the accomplishment of the on-ground geodesy works.

Providing the high accuracy of stereo images required for the definition of the plane position and terrain points heights the topographic camera TK-350 allows to obtain the resolution in the terrain of 10 m. This is not enough for the identification of the terrain objects at the production of topographic maps. That is why the"Kometa" on-board equipment includes the high-resolution camera KVR-1000. At the development of the KVR-1000 camera the structural scheme of the panoramic photo camera where the high level of the resolution which corresponds to the central part of the view filed of the objective is maintained in all the frame and the wide coverage swath could be reached was chosen. The panoramic camera KVR-1000 provides the resolution in the terrain of 2 m and the swath of 160 km. At this the area covered by one frame of TK-350 occupies 7 frames of KVR-1000 at the simultaneous switch of both cameras as it is shown in Fig. 2.

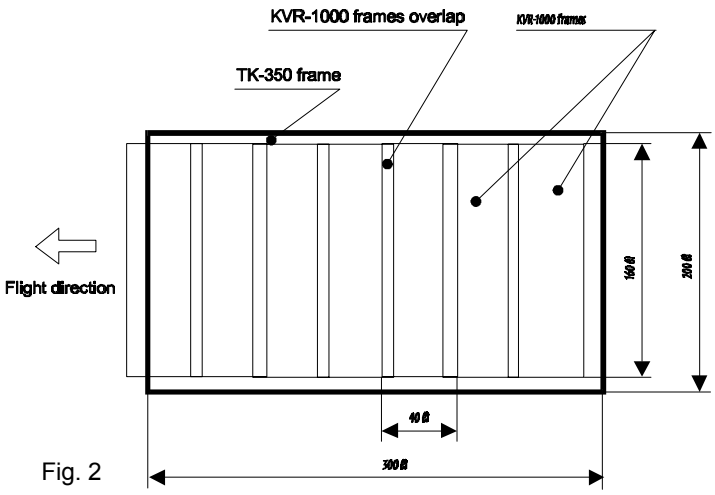

Fig. 2

Thus the space mapping system "Kometa" provides the acquisition of the topographic and identification images as well as the required measurement information required for mapping large territories. At this the accomplishment of all technological processes required at the topographic maps production is provided without the on-ground topogeodesy works.

Technological scheme of the map production.

The space mapping system "Kometa" designed and developed in Russia is the unique world space means which is specially designated for the mapping. The space images acquired by this system have the following advantages:

- Large overage – one frame of TK-350 covers the area of 60000 km2 (12 frames of SPOT or 500 frames of IKONOS), which provides the contigious coverage of large territories;
- High accuracy – the survey is carried out by the precision camera TK-350, whose dispersion and geometry parameters are calibrated with the accuracy of 1-2 ìkm.;
- Quality stereo effect – the principle of the planned survey with the overlapping of 20%, 40%, 60% and 80% providing the max quality stereo effect (in comparison with the conversion (êîíâåðãåíòíîé) survey at the ratio Â/ Í=1,05 is realised;
- Simplicity and productivity of processing – the geometric model of the camera TK-350 is the central projection which is the most simple precise and productive; the processing can be carried out by the stereo plotter and in digital stations;
- Min cost – the cost of images is lower than that of other space images of the same resolution as they cover much larger area and the cost of processing is lower because of the great economy.

At the production of topographic and thematic maps on the basis of TK-350 and KVR-1000 space images the technology at whose various phases both analogue and digital images are used is applied. Taking into account that the modern mapping and GIS production technologies are oriented mainly to the digital processing of images the analogue photos TK-350 and KVR-1000 can be digitised with the required discrete and processed in the digital form.

One of the main peculiarities of high-resolution digital images is the big volume of data (one KVR-1000 image of format 18×12 sm is 600 Mb). Therefor ZAO "Sovinformsputnik" for the operational storage of the data massifs uses the failure proof servers on the Intel platform with the volume of the disc space exceeding 170 Gb. The processing of digital images with the volume exceeding 500 Mb each is carried out in the working stations Silicon Graphs Jndigo ^{2} Hi Jxpaetu Pentium Pro under the control of the operational system IRI ×6.2 , "Windows NT" and "Windous-95" software products E Mappa, Erdas, Imagine and Photo shop.

As the topographic images TK-350 and panoramic images KVR-1000 have the geometric parameters for the DEM, ortho images and geocoded images production with the max accuracy the existing foreign software products turned out to be unsuitable. That is why Sovinformsputnik developed the software complex Ortfo Space designed for this purpose.

Thus at present there are all preconditions to acquire Russian space images of high resolution and their processing with the purpose to produce topographic and digital maps as well as GIS-products.

In accordance with these principles the technology of the topographic maps production includes the following main processes of the processing of space images:

- development of the stereo photogrammetry networks which allow to receive the plane and height reference points for any territory;
- stereo photogrammetry processing of topographic images TK-350 to obtain the relief of the terrain;
- production of ortho photo plans with the use of panoramic high resolution images of KVR-1000;
- identification of high resolution space images.

The block scheme of the technology of the map production on the basis of space images is given in Fig. 3

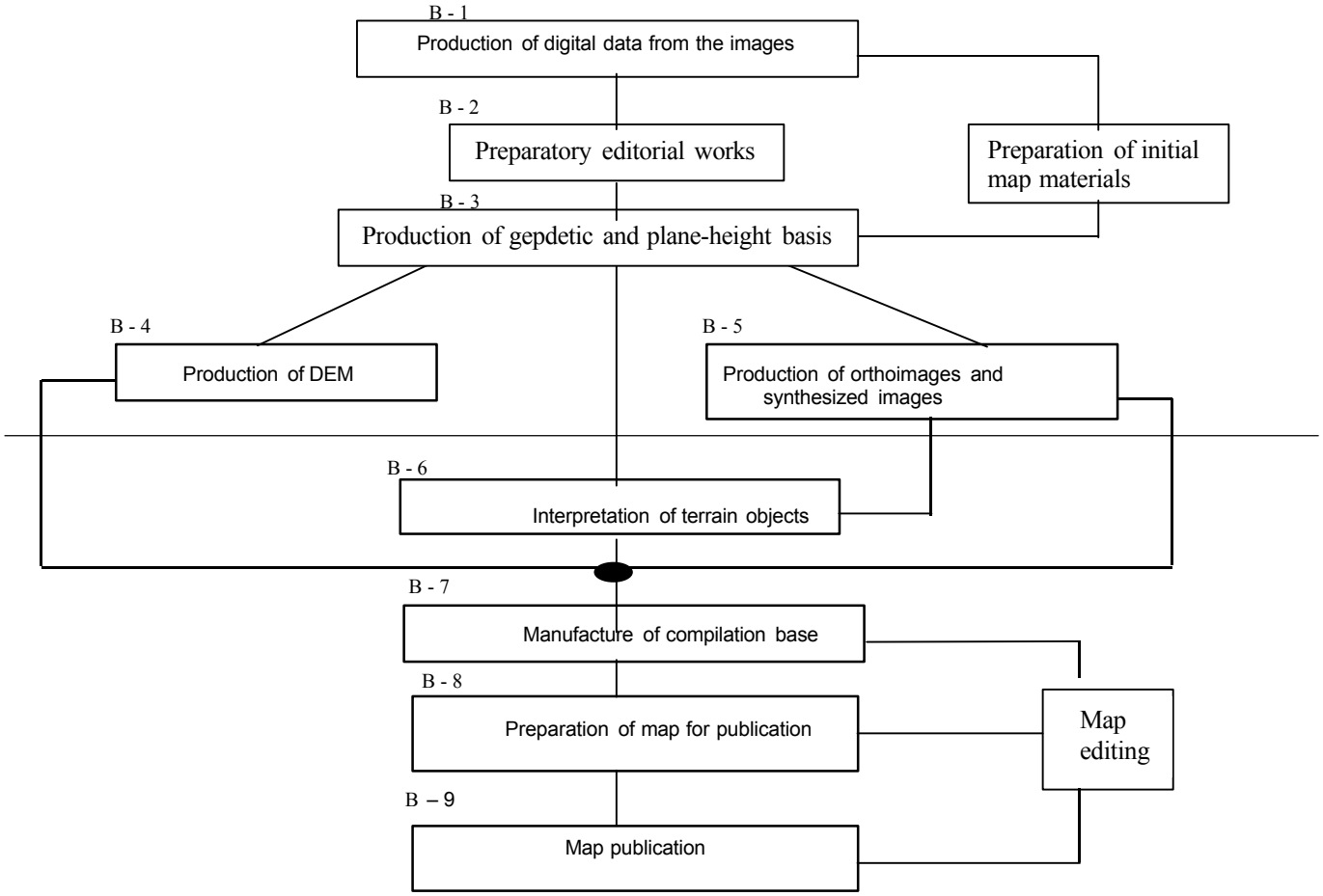

Fig.3

Let us consider the main processes of the map production in more detail.

The development of the photogrammetry network on the basis of TK-350 images.

At the mapping of vast regions which lack the geodesy and mapping basis of the required accuracy the networks are developed on the basis of TK-350 images by the photogrammetry method with the use of all the measurement information acquired by space complexes in the process of imaging.

In order to achieve the max possible accuracy of the development of the photogrammetry networks for the mapping area the terrain survey is carried out in the descending and ascending rotations with the inclinations for the ascending rotations of 65°-70°, and for the descending ones – of about 135° - 160°.

The support and inside networks are formed from these routes. The support network consists of the overlapping routes in the form of the closed polygons with the sides 700 – 1000 km., the inside network is formed of routes acquired in the ascending rotations up to the complete coverage of the terrain inside the polygons. The photographing of the support and inside routes is carried out as a rule by the scheme of the space leveling by the measurement by the laser altimeter of the altitude of the orbit above the water surface before and after the imaging route. This method provides the definition of the heights of the imaging points with the accuracy of about 3-5 m.

The photogrammetry networks are built in two phases. First the photogrammetry networks are built by the support routes for the whole continent or the big region. Then the photogrammetry networks are built by the inside routes inside one or several polygons of the support routes for the mapped area. In this case the support network is meant for the distribution of the single system of co-ordinates for the continent, its points serve as the reference basis for the inside networks and provide the grouping between the regional photogrammetry networks.

The photogrammetry networks are developed directly on the basis of TK-350 images acquired by the photo camera, which are thoroughly calibrated in a special spatial comparison unit. The errors of the definition of the calibration

parameters do not exceed 3 ìkm. Besides, in the images the grid of crosses providing the measurement of co-ordinates and the paralaxes of the image points in the form of the increments from the grid crosses is printed.

At the development of the photogrammetry network the following if available is also used besides the photographic materials and trajectory measurements:

- co-ordinates of the geodesy points identified in the images;
- heights of the points of the level;
- co-ordinates and the heights of the terrain points defined by the large scale maps and city plans;
- the shores of the oceans and seas as well as large water basins.

The process of the development of the photogrammetry network by the materials of the space imaging requires the presence of the special technology, measurement devices and high level software.

The method of building the photogrammetry network uses as a basis the strict methods suggested by Prof. Ã.Øìèä (USA) and Prof. A.Lobanov (Russia). In this method no limitations are imposed on the order of the location of routes in the image block and on the values of the mutual overlapping between images. This method allows carrying out simultaneously the building and leveling of the photogrammetry networks within many photographing routes and does not require the geodesy reference for each route.

The meaning of the method of building the photogrammetry network is as follows. For each point in the image included into the network on the basis of its measured co-ordinates in images $õ_{ij}$, y_{ij} (where i-number of the point, j-number of the image) the equations of corrections to the measured co-ordinates with the scales P_{ij} are composed. Such correction equations are composed by the co-ordinates of the imaging points, the inclination angles of the images and co-ordinates and heights of the reference points defined by the measurement mean square errors. By the correction equations by the Gauss method the normal equations are composed.

It is worth mentioning that for the network, which consists of several hundreds of images the normal equations having several hundreds of thousands unknowns appear. As a result of the solution of the system of the normal equations the designing and leveling of the network are carried out, the co-ordinates and the heights of the points which are part of the photogrammetry network with the assessment of the definition accuracy by the least squares method are determined.

This the use of the materials acquired by the space mapping system with the topographic camera TK-350 allows to develop the geodesy basis by the photogrammetry method for any land territories with any density.

The main advantage of the method is the absence of the on-ground geodesy works, which substantially reduces the cost and increases the effectiveness of the development of the geodesy basis for the hardly accessible or poorly supported territories.

The development of the plane and height basis is the first phase of the topographic map production. However it can be also the independent process of the provision by the reference points of any territories. For instance, in ZAO"Sovinformsputnik" under the AFRICOVER project the plane and height basis for the transformation of Landsat TM images for the significant territory of Africa was developed on the basis of TK-350 images. The study of the accuracy of the geometry correction of Landsat TM images showed that the number of reference points for each image is to correspond to app. 30, which provides RMS_{xy}=40 m.

Digital Elevation Models production

The topographic stereo images (stereo pairs) of TK-350 have the precise metrological support. Therefore they serve as the precise metrological basis both for the creation of the photogrammetry networks and the measurement of the relief of the terrain.

At present the developed technologies of processing space images are based on the application of the analytical stereo devices and digital photogrammetry systems (working stations).

The analytical stereo devices include the most accurate measurement devices – stereo comparison units and PC, which are conjugated between each other on the basis of the reverse communication sensors and the automatic tracking devices. The accuracy of the measurement of images with their help is about 2-3 ì km, and the presence of PC provides the possibility to achieve the max rate of the math models used in the processing. In the analytical stereo devices the film images of the terrain as the initial materials which is a certain limitation for them.

The digital photogrammetry stations are basically powerful computers equipped with the specialised software. They use terrain images presented in the digital form, which allows to automate most labour consuming processes of the

photogrammetry production: DEM production and ortho images. For this reason the digital photogrammetry stations have the most labour productivity.

The analysis of the ways to develop the photogrammetry technology in the developed countries shows that the center of attention of the modern studies is in the software and hardware developments of the digital technology. The reason is that there is a number of advantages of such means. Here belong first of all much longer list of functional possibilities and the image processing technology flexibility connected with it. Besides the analytical stereo devices are metrically unstable in time and require the realisation the complicated adjustment works. The areas required for their installation are many times larger than for the digital means. All this predetermines the prevailance of the digital processing means in the photogrammetry production.

At the organisation of the photogrammetry production it is worth taking into account however that at present the analytical stereo devices exceed by the accuracy characteristics and the quality of the images of the developed terrain stereo model all other photogrammetry devices including the working stations. That is why their application is mostly recommended at the development of the high accuracy photogrammetry networks and the obtaining of the p initial information about the orographic scheleton (îðîãðàôè÷åñêîì() of the terrain in the process of the DEM production. At the same time the production of ortho images and the DEM machine versions is most easy for the realisation with the help of digital photogrammetry stations. It is this strategy which is used by ZAO "Sovinformsputnik" at the organisation of its photogrammetry production which is based on the application of the digital means.

For the implementation of the digital methods of the photogrammetry processing of space images TK-350 and KVR-1000 the experts of ZAO "Sovinformsputnik" together with the Russian institute GosNIAS developed the digital photogrammetry system "Ortho/Z-space" oriented towards the PC use.

The functional module "Z-Space 2.0", which is part of this system, is designed for the automatic production, editing and integration of DEM on the basis of TK-350 images. The module allows accomplishing the automatic DEM production in the form of the regular matrix of heights, which at the production of topographic pair could be presented in the form of contours. The module "Z-Space 2.0" is characterised by the high rate of the generation of DEM in the automatic mode (up to 150 points/s) and the possibility to edit the machine version of DEM in the automatic and interactive modes. The accuracy of the correlation of the identical points of the stereo pair at the acquisition of the DEM heights is 1-2 pixels.

Ortho photo plans production.

The orthorectification of images is the important phase of the development of the topographic maps. At the mapping in the max large scale the ortho plans are developed on the basis of the high resolution images KVR-1000. Though these images are panoramic and have big distortions, due to the precision design of the KVR-1000 camera and the calibration of all the required parameters the acquisition of the high accuracy ortho images suitable for the production of the large scale (up to 1:10000) photo plans and ortho photo plans is provided. At this at the geodesy referencing of the digital images KVR-1000 the corrections for the dynamic distortions, eccentricity of the rotation of the axis of the scanning mirror, the sift of the main point of the image, the static and panoramic distortion, the shift and deformation of the photo film are made.

For the production of ortho photo plans in ZAO "Sovinformsputnik" the "Orthospace 1.2" module was developed. The functional module "Orthospace 1.2" is designed to produce ortho images and composite colour ortho images on the basis of space images KVR-1000, MK-4, KFA-1000, TK-350 and Landsat TM as well as on the basis of frame and panoramic aero images. Depending on the composition of the initial data two working modes of the module are possible: geometric correction and full orthorectification of the initial images.

The geometric correction of images is carried out by their transformation into the horizontal plane. The height of the given plane corresponds to the average altitude of the relief of the mapped part of the terrain. This mode is very economical and recommended for the processing of the images of the hilly terrain and the desert areas.

He complete orthorectification of the image is carried out on the basis of the DEM. In the process of the transformation of the image the influence of its inclination angles, the curvature of the Earth, the movement of the film and the carrier at the moment of the exposure of the frame is taken into account. The accuracy of the processing of the initial images by "Orthospace 1.2" is 1-2 pxl. That allows to produce ortho images on the basis of KVR-1000 images with the following accuracy characteristics:

$RMS_{x,y} = \pm 2 – 3$ ì at the use of reference points from TK-350 images.

$RMS_{x,y} = \pm 2 – 3$ ì at the use of additional GPS-points.

The functional module "Orthospace 1.2" includes also the geodesy calculator " Geospace" used at the preparation of the working project. It realises the functions of the recalculation of the co-ordinates of the points in the geodesy

systems of various countries. With its help it is possible to carry out the mutual recalculation of co-ordinates in 200 local ellipsoids and datums, the mutual transformation of the most frequently met mapping projections: Gause-Cruger, UTM, Lamberth and stereoscopic one.

Identification of the objects of the terrain

Providing the 2 ì resolution in the terrain KVR-1000 images allow to identify the objects of the terrain required to provide the required fullness of the contents of the topographic maps of the scale 1:50000. At this the main peculiarity of the identification of space images is the absence of the materials of the field inspection.

At the identification special attention is paid to the following:

- direct and indirect identification signs especially of the terrain objects which are hard to be identified;
- ways and methods of the acquisition of the qualitative and quantitative characterstics of the objects;
- lists of terrain objects unidentified directly by the photos and of the sources by which these objects can be placed;
- lists of objects which are to be identified by the season images (photos);
- order of the use of the data bank of the identification templates;
- norms of the selection of the objects;
- the rules of the reflection of the objects which are of the ambiguous interpretation and so on.

For the known (accessible) areas the list of the objects of the terrain which can be met in the mapped area is processed. The direct and indirect identification signs of these objects are established. By the extrapolation of these signs the template data bank for the analogue areas is developed.

The formalisation of the identification results and the subsequent processes of the establishment, preparation for publishing, editing and issue of maps are of more traditional character and will not be considered here in detail.

Conclusion.

Thus the use of Russian space images of high resolution and accuracy allows to foreign and domestic consumers to effectively solve multiple tasks to develop topographic, digital and thematic maps. The use of TK-350 and KVR-1000 images allows to produce topographic maps of the scale 1:50000 with the mean square errors in plane 20 – 25 m and in height 10 m. KVR-1000 images allow developing photo plans and ortho photo plans of the scale up to 10:10000 with the mean square w error of 7-10 m in plane. The space mapping system “ Kometa” enables to realise projects to produce maps starting with separate patches of the terrain up to separate countries and regions.

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