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Analysis of errors in the creation and updating of digital topographic maps

Vera Yartseva[1]*, Olga Besimbaeva[2], Elena Khmyrova[3]

[1,2,3]Karaganda State Technical University
Mining Faculty, Mine Surveying and Surveying Department
Bulvar Mira 56, Karaganda, Kazakhstan
[1]e-mail: sabitovavera@inbox.ru, [2]e-mail: bog250456@mail.ru
[3]e-mail: hmyrovae@mail.ru, ORCID: https://orcid.org/0000-0003-3015-0280

*Corresponding author: Vera Yartseva

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Abstract: This article analyzes the technology of creating and updating a digital topographic map using the method of mapping (generalization) on an updated map with a scale of 1 : 25,000 based on the source cartographic material. The main issue in the creation of digital maps is the study of map production accuracy and error analysis arising from the process of map production. When determining the quality of a digital map, the completeness and accuracy of object and terrain mapping are evaluated. The correctness of object identification, the logical consistency of the structure, the and representation of objects are assessed. The main and the most effective method, allowing to take into account displacement errors for the relief during image processing, is orthotransformation, but the fragment used to update the digital topographic map needs additional verification of its compliance with the scale requirements of the map. Instrumental survey will help to clearly identify areas of space image closer to nadir points and to reject poor quality material. The software used for building geodetic control network should provide stable results of accuracy regardless on the scale of mapping, the physical and geographical conditions of the work area or the conditions of aerial photography.

Keywords: mapping, source cartographic material, errors, orthotransformation, instrumental survey

1. Introduction

Using the newest types of surveying systems, the transition to computer technologies and information systems allows people to receive digitally and store topographical information. A digital electronic map (DEM) is a combination of a digital terrain model (DTM) and several digital situation models. Each digital situation model is a layer of DEM. All layers of DEM are superimposed on DTM. Digital maps contain much more information than traditional graphic maps, thanks to layered storage. In addition, unlike traditional models, they are not physically obsolete. Information about terrain is supported by continuous monitoring in the 21st century. Creation of DTM requires an investigation of the construction accuracy and error analysis of the map production process.

To solve this problem, the following works were thoroughly studied and analyzed: Basargin (2014) Creation of digital models of mineral deposits with application of modern technologies; Dzyuba (2000) Methods of preparation and use of raster map materials; Myshlyaev (2005) Estimation of the accuracy of digital orthophotomaps.

2. Methods and Data

The object of the study was the technology of creating digital topographic maps based on graphic originals and updating them, for example, on scales 1 : 25,000 and 1 : 50,000. The creation and updating of digital topographic maps on a scale of included 2 stages. The first stage requires DTM creation on a 1 : 25,000 scale based on source cartographic material (SCM). In the second stage DTM updating, there are some layers: geodetic points; settlements, industrial, agricultural and socio-cultural facilities; railways and highways; hydrography, relief, vegetation and soils, and borders. The creation and updating of digital topographic maps revealed discrepancies in the mapping of terrain and in solid contour positions of the same territory on maps of 1 : 25,000 and 1 : 50,000 scales. Therefore, for the creation of digital topographic maps on 1 : 50,000 scale the method of mapping (generalization) was chosen using an updated map with a 1 : 25,000 scale.

We consider the discrepancies shown in Figures 1–3. Bright colors of the electronic map are elements with a scale of 1 : 50,000, and a raster image of the updated map of scale 1 : 25,000 is shown below.

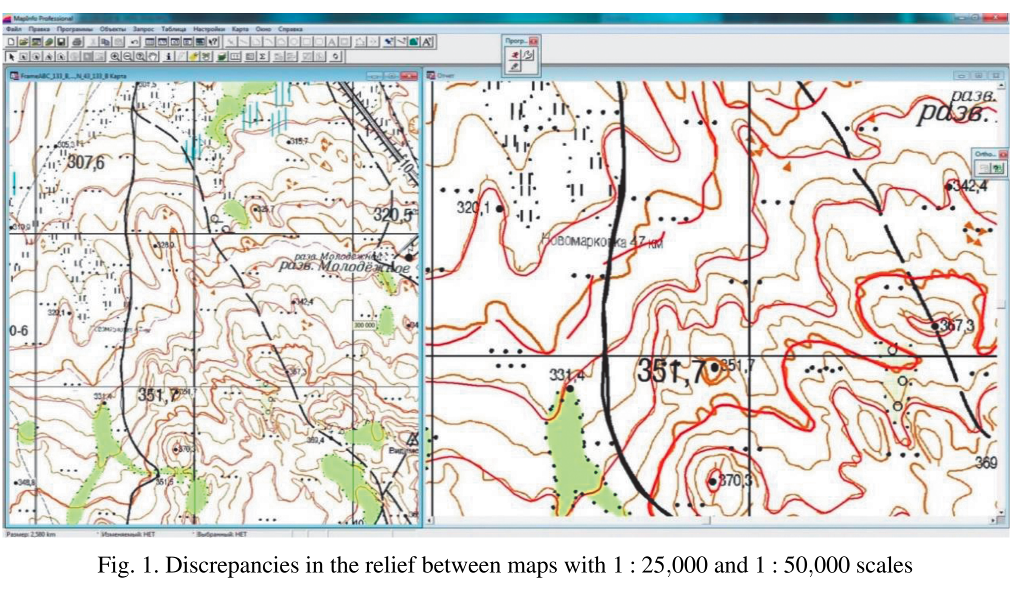

Fig. 1. Discrepancies in the relief between maps with 1 : 25,000 and 1 : 50,000 scales

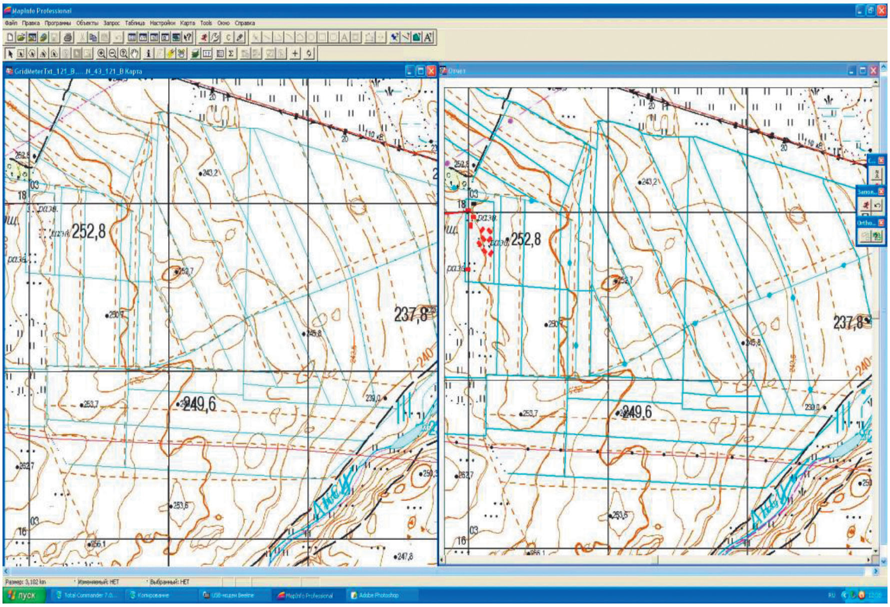

Fig. 2. Discrepancies in hydrography between maps with 1 : 25,000 and 1 : 50,000 scales

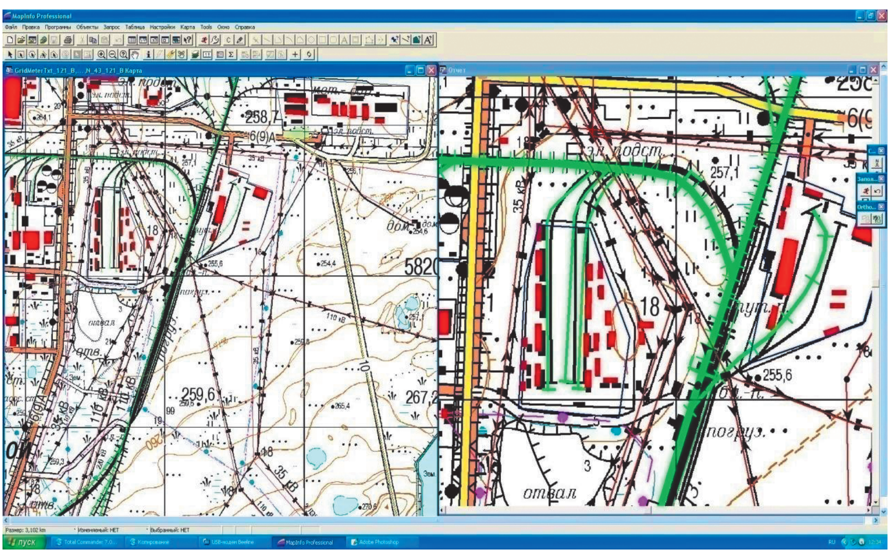

Fig. 3. Solid contour discrepancies between maps with 1 : 25,000 and 1: 50,000 scales

It is necessary, first, to conduct research regarding in the possible reasons for given discrepancy occurrence in digital versions of topographic maps. For this, it is necessary to analyze the technology of creating and updating a digital topographic map and possible errors that arise during work on this technology.

Since the process of updating and creating a digital map on the scale of 1 : 25,000 required original cartographic material, and meaning paper documents, storage conditions of such materials should also be investigated.

The storage system includes: the creation of a material and technical base with the provision of an archive room; maintenance of documents' physical and chemical safety in accordance with the requirements for temperature-humidity, light, sanitary-hygienic, a security regime and fire safety; and use of a special storage facility (racks, safes, boxes, etc.) (Gogoleva, 2009). In the storage room, the temperature-humidity regime, which is optimal for documents, should be maintained, according to their specificity. In a storage room equipped with an air conditioning system, a temperature should be 17–19°C and an air humidity should be 50–55%; in a storage room with an uncontrolled climate, i.e., in a heated room with natural or forced air exchange, the air parameters can be varied: 10–30°C, air humidity – 30–60%. The storage room does not allow a sharp fluctuation of temperature and humidity, as this destroys the information carrier (Gogoleva, 2009). Failure to comply with the rules of document storage leads to their deformation, which leads to a loss of information content within these documents and the appearance of errors in further work with them.

When checking the quality of source cartographic material, the accuracy of the mathematical basis is verified (the dimensions of the sides and diagonals of the topographic maps should not differ by more than 0.2 and 0.3 mm from the dimensions of the standard trapezoid). For source materials, proposals for deviation from the requirements, separate editorial decisions are made, which are recorded in the forms of digital and electronic cards (EC) (Dzyuba, 2000).

The preservation of cartographic heritage has long advocated the transformation of maps or, more specifically, of transferring paper maps produced by analogue methods into a digital format. The development of GIS techniques and cartographic databases has allowed increasingly rapid georeferencing of scanned maps into global datums like WGS84. The prerequisite for good georeferencing is, however, good digital transformation of the paper map formating. This is, of course, a technical issue, but it also has some mapping implications connected with the cartographic generalization theory (Favretto, 2014).

Countries that have moved from traditional paper maps to electronic versions have converted them by scanning and digitizing them. Consequently, geospatial database of almost every country stores data obtained by this method. As a result, it is necessary to analyze the accuracy of this technique. Discrete binarization process must be ensured in order to maintain the integrity of time and qualitative performance indicators. Discreteness of scanning should be the same on all original documents, (usually 500 dots per inch, but not less than 300 dots per inch). Deviations from the recommended values of the discreteness of scanning can lead to deterioration in quality and loss of electronic map accuracy (if the discreteness is less than recommended one) or to an unreasonable increase in the time required for creation of an electronic map (if discreteness is higher than recommended) (Gogoleva, 2008).

The completeness and quality of scanning are checked by a method of visual comparison of the raster image on the monitor screen with source cartographic material. All elements of the source cartographic material must be on the raster image, and the image must not have tears, greases, and extraneous stains. Quality control as it relates to scanning includes monitoring the accuracy and completeness of scanning, as well as assessing the quality of the raster image. The scanning accuracy is controlled by measuring the frame and diagonals of the cartographic material raster image. Deviations should not exceed 0.2 mm from the actual dimensions (Dzyuba, 2000).

The factors determining the accuracy of scanning are: the resolution of the scanner; the inaccuracy of the continuity of the scanned material to the surface of the glass of the flatbed slide; rotation of the tablet relative to the motion of the scanning beam; errors in determining the intersection points of the grid lines.

Transformation of raster cartographic material is necessary to eliminate information errors; to solve scanning errors; for conversion into production projections; and for an alignment of different map layers. Transformation of the raster image is performed on the map frame (with or without the deflection frame points depending on the scale of the created electronic map) or on frame and transformation points (Dzyuba A., 2000). Transformation of a raster image can not completely eliminate source cartographic material errors and scans, since the number of transformation points is limited, and any transformation method introduces its own errors.

Further work in vectorization programs and GIS is related to the vectorization of the raster image and replenishment of the digital topographic map with other source data. Some sources of error in GIS data are very obvious, whereas others are more difficult to notice. GIS software can make the users to think that their data is accurate and precise to an unreasonable degree. Scale, for example, is an inherent error in cartography; depending on the scale used, one could be able to represent different types of data, in different quantities and with different levels of quality. Cartographers should always adapt the scale of work to the level of detail needed in their projects (Manuel and Pascual, 2011).

High-resolution scanner space images are more often used to update the digital topographic map, but their georeferencing is performed on reference points without photogrammetric processing. Space scanner imaging systems are equipped with long-focus lenses, and the beam of rays registered by them is indeed much narrower than in the case of an aerial camera. However, the deviation angle α of the optical axis from the nadir can be tens of degrees. When determining the planned location of the terrain point from the image, the error value ΔL caused by the deviation ΔH of the height of this point from the mean value (more precisely, from the height of the points used for geo-referencing of the image) can be calculated from:

$$\Delta L = \Delta H \cdot \tan \alpha \tag{1}$$

ΔH – height of the points used for geo-referencing of the image, α – the deviation angle of the optical axis from the nadir.

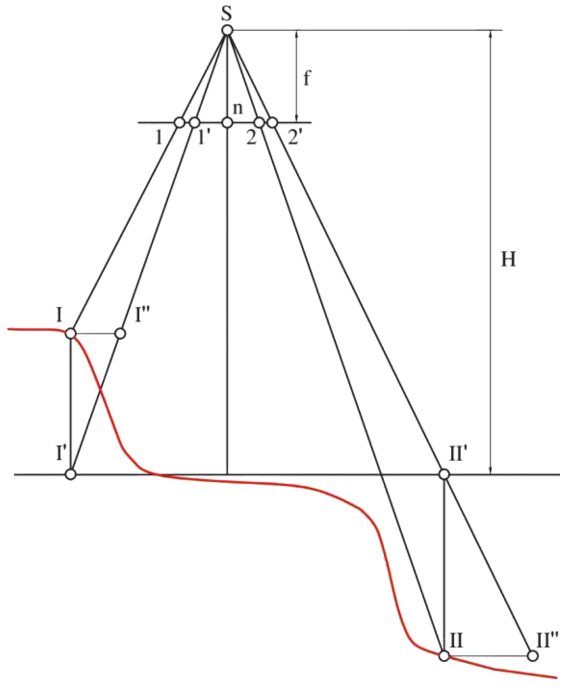

Fig. 4. The displacement of points on space image, due to the terrain

Where: S – nadir; n – point of zero distortion on space image; f – focal length of photographic lens; H – height of the points used for geo-referencing of the image; I, II – points on terrain; I′, II′ – orthogonal projection of points; I–I′, II–II′ – deviation from the height of the points used for geo-referencing of the image (ΔH); 1, 2 – points position on space image; 1′, 2′ – orthogonal points position; 1–1′, 2–2′ – planimetric error on space image; I–I″, II–II″ – planimetric error on terrain (ΔL)

3. Results

Table 1 shows the values of the planned error ΔL depending on the type of terrain (from plain to mountain) and the angle α. Thus, the implementation of orthorectification taking into account the terrain model is always a necessary condition for obtaining high-precision output products (except for shooting flat terrain or using nadir image, the provision of which data providers do not guarantee) (Dzyuba, 2000).

Table 1. The error in determining the planned position of the terrain points from an image that has passed affinity geo-referencing

The angle of deviation from nadir, α	Height deviation from the mean value, ΔH [m]				
	2	10	50	100	500
5°	0	1	4	9	44
15°	0.5	3	13	27	134
25°	1	5	23	47	233

During photogrammetric processing, a correspondence is established between the points on the image and similar points located on the earth's surface. This eliminates the geometric distortion of the image. The main and most effective method is orthorectification, which takes into account bias relief errors during image processing. The effect of such displacements is particularly critical for images of terrain, the relief of which is characterized by significant differences in altitude (see Table 1).

Digital topographic maps have a seperate quality assessment system. In determining the quality of the digital topographic maps, the following indicators are evaluated (Requirements for quality of digital topographic maps, 2000):

– completeness;
– accuracy;
– correct identification of objects;
– the logical consistency of the structure and objects representation.

DTM accuracy is checked using source cartographic material as a raster substrate and evaluated by deviations of DTM objects (including contours) in the horizontal plane relative to the corresponding objects on the SCM (Requirements for quality of digital topographic maps, 2000). The frame sides and diagonal dimensions of the map nomenclature sheet of DTM must correspond to theoretical values; deviations are not allowed. The location accuracy of the DTM objects in the horizontal plane in relation to SCM should meet requirements for topographic maps on an appropriate scale. The mean squared errors of the point object positions, on the DTM should not exceed 0.1 mm in the scale of the DTM, relative to corresponding objects of the SCM. The acceptable values for mean square errors of the solid contour position in the composition of the DTM relatively to the correspondence of the SCM contour are given in Table 2 (Dzyuba, 2000).

Table 2. The acceptable values for mean square errors of the solid contour position (DTM scale)

DTM scale	Mean square errors of the solid contour position relatively to the SCM, mm, in the regions	
	flat	mountain, highland and desert
1 : 10,000–1 : 100,000	0.20	0.30
1 : 200,000	0.15	0.20
1 : 500,000	0.10	0.10
1 : 1,000,000	0.10	0.10

When assessing the quality of digital topographic maps on a 1 : 25,000 scale, the permissible deviations from the original cartographic material are: point objects – 0.1 mm; solid contours in flat areas – 0.2 mm, Solid contours in mountain areas – 0.3 mm. (Table 2). Therefore, these requirements must be met by satellite images when updating the DTM. The images of the first stage of geographic integration are used to update a 1 : 25,000 scale digital topographic map. In such images, the complicating influence of numerous details is excluded, typical features and main landmarks of the terrain, such as forms of mesorelief, are revealed. We will use the deviation values of only solid contours, due to the difficulty of identifying point objects on images of this rank. Accordingly, the permissible deviation of a solid contour in a flat terrain for a scale of 1 : 25,000 is 5 m; on this basis, images selected in italics in Table 1 will be suitable for updating the DTM.

If it is impossible to obtain images of the required parameters, the fragment used to update the DTM needs additional verification of its compliance with the requirements of the scale of the DTM. Additional instrumental surveys of this image will help to reject low-quality material. It is suggested that this check should be carried out on solid contours; on images of this level identification is not difficult. After finding out the coordinates of the characteristic points (nodes) from the space image, which is transformed and geo-referenced, compare these values with the results of ground-based geodetic surveying of the corresponding points on the terrain. If the deviations are within the accuracy of the DTM, the space image can be considered appropriate for the update process.

4. Conclusions

The orthoimages, which were obtained from the space image's sections, located closer to the nadir points, and also the hypsometric coloring of the area of the orthophoto, in accordance with the distance from the nadir point of the photographic section, are used to minimize errors (Myshlyaev, 2005). Technological analysis of digital map creating based on the original graphics show that a number of factors influence the DTM accuracy. Failure to observe the rules for storing documents leads to deformation and loss of SCM quality, thus introducing errors into the process of further creating a digital map, and the complete loss of the document deprives users of the main source of information about cartographic territory. The transformation of a raster image can not completely eliminate SCM errors and scanning, since the transformation is aimed at reducing the discrepancy between the coordinates indicated in the "Geographic Calculator" program and taken from the topographic map by stretching the raster image.

An additional ground-based geodetic survey aimed at sorting out the update materials will improve the quality of their data.

In the event of a discrepancy between the information obtained with the SCM and data of land, aerial and space survey, the accuracy analysis of the updated map and the choice of the DTM creating method should be made (Besimbayeva, 2014).

In modern production, digital methods of collecting topographic information about the terrain are basic, and received information is stored and transmitted by the user in digital form. Therefore, photogrammetric software must be based on rigorous mathematical solutions of photogrammetric problems and allow to realize geometric accuracy of analog or digital images taking into account their projection, scale, measuring and visual qualities.

The software used for constructing geodetic control networks should provide stable results of accuracy, regardless of the scale of the mapping, the physiographic conditions of the mapping area and the conditions for aerial photography.

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