DETERMINATION OF THE ERROR OF MEASURING THE HEIGHTS OF THE OBJECTS DURING THE AUTOMATIC PROCESSING OF STEREO PICTURES

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Abstract: Currently, information on the spatial description of objects is used in many areas of human activity. One of these types of information is the coordinates of objects. Such data are used in cartography, in the construction of digital maps and 3D models, for the operation of navigation aids, etc. In the automated creation of digital models of terrain relief, one of the main qualitative indicators is the accuracy of determining the height of objects. The main influence on this indicator is made by the parallax measurement error when processing stereo images. To obtain a formula for calculating the accuracy of measuring the height of objects, let's use the expansion of the function in a Taylor series. Using the Cramer-Rao formula for the potential accuracy of measuring the coordinates of the image of the object in the image, the Fourier transform and Parseval's equality, the formula for the potential accuracy of combining stereo images (parallax measurements) is obtained. The analysis of the obtained formulas shows that the image alignment accuracy deteriorates with an increase in the noise power spectral density in the first and second images and a decrease in the similarity of one image to another, as well as with a decrease in the effective width of the mutual spatial spectrum of stereo images. As the value of the stereo recognition basis increases, the error in measuring the heights of objects first improves, and then worsens. This deterioration is due to the fact that stereo pair images are obtained from different spatial points and at the same time perspective distortions and distortions in relief appear on the images. Accordingly, with an increase in the basis of shooting, these distortions will increase. This approach can be used when planning the mode of stereo shooting and equipment for removing the earth's surface for mapping, obtaining 3D models, etc.

Keywords: photogrammetry, height of objects, accuracy of obtaining the coordinates of objects, stereo images, parallax, correlation-extreme method.

1. Introduction

At present, coordinate information about objects located on the earth's surface is necessary for constructing digital terrain models (DTM) and relief (DRM), implementing geoinformation projects, as well as in georeferencing of Earth remote sensing data (Earth remote sensing). One of the main sources of such information is stereo images obtained from various aircraft (spacecraft (SC), airplanes, helicopters, unmanned aerial vehicles (UAVs)) [1].

One of the main indicators affecting the quality of the obtained DRM is the accuracy of obtaining the coordinates of objects.

There are many software products for building and analyzing DRM. These are such GIS packages and modules as Spatial Analyst, 3D Analyst, ArcGIS packages, MapInfo programs (MapInfo Corp.), Autodesk Map 3D AutoCAD systems (Autodesk Inc.) and others. Common to them is the automation of DRM construction, including the combination of stereo pair images, which is necessary for measuring the heights of objects [2, 3].

When creating a DRM of the earth's surface, one of the main qualitative indicators is the accuracy of determining the height of objects [4]. It is this indicator that affects the quality of a digital card and, as a result, the probability of solving problems using DRM.

The sources of information for building the DRM and DTM are topographic maps, stereo pairs of aerial and satellite images, radar data, etc.

With the automatic [5] removal of coordinate information about the terrain and the objects located on it from stereo images, it is necessary to have techniques that would provide an opportunity to evaluate the accuracy of determining the coordinates of objects. These techniques should take into account all factors affecting the accuracy of determining coordinates. Particular attention must be given to the accuracy of determining the height of objects, since it is always worse than the accuracy of determining other coordinates due to the use of not one, but two pictures. Moreover, a significant influence on the error of measuring the height of objects during automatic combination of stereo images is the accuracy of parallax determination [4].

2. Methods

The main difficulty in obtaining an analytical expression for the accuracy of determining the height is the parallax measurement error, that is, the difference in the coordinates of the same point in the first and second pictures of the stereo pair. Since stereo images are combined automatically using the appropriate software products [6], which were discussed above, when evaluating the accuracy of parallax measurements, it is necessary to take into account the correlation coefficient of images in the first and second images. For this, the research uses the Cramer-Rao formula for the potential accuracy of measuring the coordinates in the image, as well as the direct and inverse Fourier transforms.

3. Results

The formula for calculating the height of objects from stereo images, in a general form, has the form [4]:

$$h = \frac{H^2}{Bf} p, \tag{1}$$

where H, B, f, p – the flight altitude of the aircraft, the basis of stereo imagery, focal length and parallax, respectively.

Let's take, as a first approximation, an additive model of the influence of errors in determining the variables included in this formula. After expanding this function into a Taylor series in the corresponding variables, let's obtain the variance of the error in determining the height:

$$\sigma_h^2 = \left(\frac{dh}{d\delta_p}\right)^2 \sigma_p^2 + \left(\frac{dh}{d\delta_B}\right)^2 \sigma_B^2 + \left(\frac{dh}{d\delta_H}\right)^2 \sigma_H^2 + \left(\frac{dh}{d\delta_f}\right)^2 \sigma_f^2, \tag{2}$$

where σ_p, σ_H, σ_B, σ_f – the standard deviations (SD) of the parallax measurement errors, the flight altitude of the aircraft, the stereoscopic basis, and the focal length, respectively.

Currently, SD errors in measuring the flight altitude of the aircraft, the basis of stereo imagery and focal length, as a rule, are known with fairly high accuracy.

The main influence on the accuracy of determining the height of objects during automatic processing of images is the accuracy of determining parallax. When measuring parallax, the task is reduced to searching and detecting the image of an object in the second image from the image of this object in the first image and measuring its position against the background of images of other objects and noise [3].

It should be borne in mind that when taking pictures on the latter, promising distortions arise [4]. After eliminating this kind of distortion, the image will remain distorted due to the relief, the elimination of which is possible only when the SD is known.

Thus, during processing, the mutual distortions arising from the action of noise and distortion during relief should be taken into account in images on two adjacent images.

The accuracy of determining parallax during automatic processing of stereo images will be determined by the accuracy of combining images of the environment of the point in the first and second images. This processing is carried out against the background of noise introduced by the optical receiver, the sampling process, etc. [7]. The task is complicated by the fact that noises are present in both the first and second pictures. The reference image (the environment of the selected point), which is searched for in the second image, is distorted by noise.

Stereopair snapshots can be combined using several methods. Snapshots are one of the most complex signals. The most general method that can be used for almost any signal is the extreme correlation method. With this method, the decision is made on the absolute maximum of the cross-correlation function [8] at the output of the solver. At the same time, the signal-to-noise ratio in the images is of great importance [3, 9].

Using the Cramer-Rao formula for the potential accuracy of measuring the coordinates of the image of the object in the image, the Fourier transform and Parseval's equality, the formula for the potential accuracy of combining stereo images (parallax measurements) is obtained

$$\sigma_p^2=\frac{2q_1+2q_2+1}{4k_{12}^2 q_1 q_2 \overline{\omega^2}}, \quad (3)$$

where q_1, q_2 – the signal-to-noise ratio in the first and second images, respectively, E_{12} – the energy of the mutual spatial spectrum of the images,

$$k_{12}=\frac{E_{12}}{\sqrt{E_1E_2}};$$

– the correlation coefficient of the spectra of the images of the object in the first and second pictures,

$$\overline{\omega^2}=\frac{\int_{-\infty}^{\infty}\omega^2 F_1(j\omega)F_2^*(j\omega)\mathrm{d}\omega}{\int_{-\infty}^{\infty}F_1(j\omega)F_2^*(j\omega)\mathrm{d}\omega}; \quad (4)$$

– second moment of the mutual wide spectrum of the image [10].

4. Discussion and conclusions

An analysis of formula (3) shows that the image alignment accuracy deteriorates with an increase in the noise power spectral density in the first and second images and a decrease in the similarity of one image to another, as well as a decrease in the value ω^2 characterizing the effective width of the mutual spatial spectrum of the images.

In order to analyze the influence of the corresponding parameters on the error in determining the heights of objects, the initial data are taken as typical data that correspond to the parameters and characteristics of modern spacecraft for remote sensing of the Earth (**Fig. 1**).

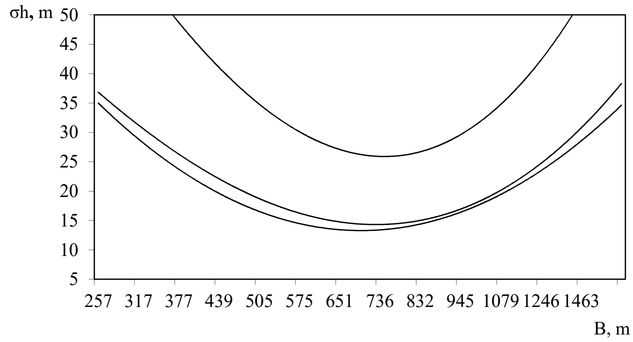

Fig. 1. Graph of the error in determining the heights of objects on the value of the stereo shooting basis

The graphs of the dependences of the error in determining the heights of objects on the value of the stereo recognition basis are presented in **Fig. 1**. Analysis of the graphs shows that with an increase in the basis value, the error in measuring the heights of objects first improves and then worsens. This deterioration is caused by the fact that stereo pair images are obtained from different spatial points and at the same time perspective distortions and distortions in relief appear on the images [4]. Accordingly, with an increase in the basis of shooting, these distortions will increase. Due to this, the energy of the mutual spatial spectrum of images (4) decreases (**Fig. 2**).

A decrease in the energy of the mutual spatial spectrum of the images leads to a deterioration in the parallax determination error when the stereo images are automatically combined by the extreme correlation method (**Fig. 3**).

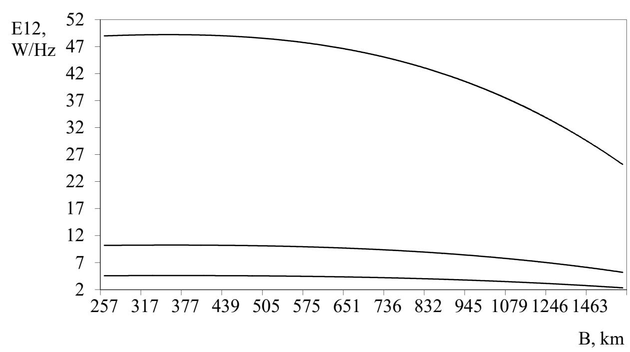

Fig. 2. The graph of the dependence of the energy of the mutual spatial spectrum of the images on the value of the stereo shooting basis

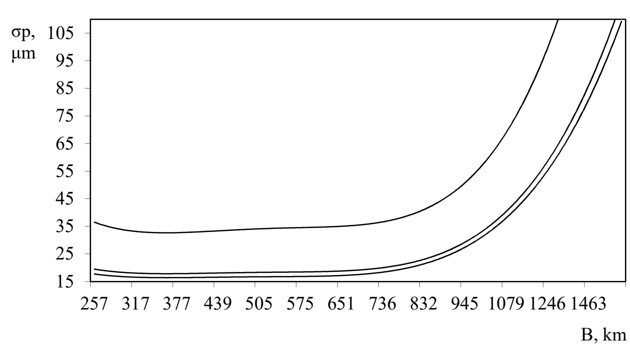

Fig. 3. The dependence of the parallax determination error on the value of the stereo shooting basis

This, in turn, leads to deterioration in the accuracy of determining the heights of objects.

The advantage of this approach is the use of a finite analytical expression. It provides an opportunity to calculate the potential accuracy of determining the heights of objects in cases of DRM construction using modern applications.

The disadvantages include the difficulty in calculating the moments of the mutual spatial spectrum of stereo images.

This approach can be used when planning the shooting mode and equipment for removing the earth's surface for mapping, obtaining 3D models, etc.

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