

Application of non-metric digital cameras to control the volume of soil displaced when performing earthworks

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Abstract. Moving soil during earthworks at a construction site requires its accounting and control. For this, expensive geodetic methods are widely used, while accounting and control must be performed with high accuracy and frequency. In practice, the use of terrestrial stereophotogrammetric survey can provide a high frequency and accuracy of the results obtained. The traditional stereophotogrammetric survey at this stage undergoes significant changes with the introduction of digital technologies, which allow it to be used more widely. It is proposed to use non-metric digital cameras when performing terrestrial stereophotogrammetric surveys, which will let to reduce the cost of performing the measurement works, as well as to increase the efficiency of field works. The main indicator of the possibility of using the non-metric digital cameras is their resolution, which allows ensuring the accuracy of definitions and acceptable parameters for their calibration.

1 Introduction

Determining the volume of earthworks and drawing up a scheme for moving soil are mandatory elements of a vertical design project. In most cases, the production of various types of engineering works related to the movement of soil, there is a need to determine the volume of earthworks (Fig. 1). The requirements for the accuracy of determining the volume of soil transported are due to the cost of excavation.

Such a need arises during the recultivation of oil-contaminated soils, when contaminated soil has to be transported to the polygon for its cleaning. The use of traditional geodetic methods in determining large volumes of stored oil-contaminated soil is always problematic due to its inaccessibility associated with the presence of oil residues in it. In practice, the customers and contractors are always faced with the question of the reliability of obtaining the initial information on the scopes of the works performed, including the scope of earthworks. Currently, the performers determine the scope of excavation works by taking into account the displaced soil and confirm it with well-known geodetic methods. However, it is practically impossible to fix the stakes, rails or reflectors on the stoked soil for a long time, which leads to a loss of accuracy of geodetic measurements.

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In large enterprises with a large scope of earthworks, the photogrammetric method is used. The obviousness of the effectiveness of the photogrammetric method in solving the applied tasks using traditional technology was largely constrained by the complexity of obtaining the initial information (obtaining images and their primary processing) and the complexity of their photogrammetric processing (the presence of photogrammetric devices and the software).

The use of the photogrammetric method to determine the volume of contaminated soil lets to avoid such problems. Modern digital photogrammetric cameras for this type of definition are not widely used due to their high cost. Let's consider in this paper the possibility of using the non-metric digital cameras to determine the volume of earthwork.



Fig. 1. Excavation works during the construction of the pit.

2 Materials and methods

Currently, in the area of large-scale mapping (which is fundamental in solving many applied tasks, including the determination of the scopes of earthworks), rapid changes are taking place related to the development of a number of key technologies for collecting and processing spatial data.

Despite the preservation of the theory of the basic principles of ground-based photogrammetry technology [1], its individual stages underwent dramatic changes; digital cameras appeared, the whole process of image processing moved to the plane of analytical photogrammetry on a PC. All this allows to apply wider the photogrammetric methods in practice.

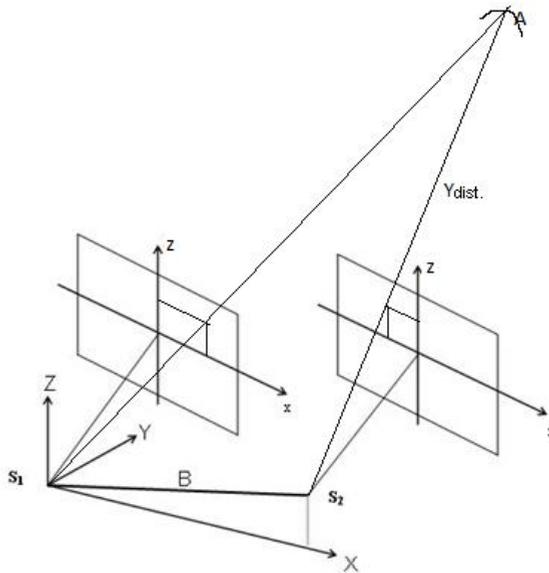


Fig. 2. The normal case of terrestrial stereo shooting.

In order to determine the coordinates of terrain points from a pair of ground images, well-known connections of the geodetic coordinates of terrain points with their measured coordinates in the image are used [2]. So, for the normal type of shooting fig. 2, the most commonly used in practice, these connections are of the form:

$$\begin{aligned} X^r &= X_{S_1}^r + B \frac{x_1}{x_1 - x_2} \sin \alpha_1 + B \frac{f}{x_1 - x_2} \cos \alpha_1, \\ Y^r &= Y_{S_1}^r + B \frac{x_1}{x_1 - x_2} \cos \alpha_1 + B \frac{f}{x_1 - x_2} \sin \alpha_1, \\ Z^r &= Z_{S_1}^r + B \frac{z_1}{x_1 - x_2}, \end{aligned} \quad (1)$$

wherein: X^r, Y^r, Z^r – geodetic coordinates of a terrain point;

$X_{S_1}^r, Y_{S_1}^r, Z_{S_1}^r$ – coordinates of the left center of photography;

x_1, x_2 and z_1, z_2 – measured coordinates of a point on the left and right pictures of a stereo pair; B – horizontal laying of the basis of photographing.

According to the measurement results using a stereo pair, the width of the berm L is determined, the height of the berm h and calculate its volume V . The width of the berm is determined as the distance between opposite points of its boundary:

$$L = \sqrt{\Delta X^2 + \Delta Y^2}, \quad (2)$$

wherein, $\Delta X, \Delta Y$ – differences between opposite points of the berm boundary. The height of the berm h is defined as the difference between the base of the berm and its apex:

$$h = Z_{\text{apex}}^r - Z_{\text{base}}^r. \quad (3)$$

If the berm does not have the correct geometric shape, then several sections are constructed with the interval D_1 between them to determine its volume. The area of each

cross section P_i is determined, and then the volume of the berm is determined by the formula:

$$V = \sum_{i=1}^m \frac{P_i + P_{i+1}}{2} \cdot D_i. \quad (4)$$

Moreover, the accuracy of determining the coordinates of the points of the berm or excavation is estimated by the formulas:

$$\begin{aligned} m_X &= \frac{Y}{f} \sqrt{m_x^2 + \frac{x^2}{p^2} m_p^2}, \\ m_Y &= \frac{Y}{p} m_p, \\ m_Z &= \frac{Y}{f} \sqrt{m_x^2 + \frac{z^2}{p^2} m_p^2}, \end{aligned} \quad (5)$$

wherein: m_X , m_Y , m_Z - standard deviation of determining the coordinates X, Y, Z of the terrain;

m_p - standard deviation of parallax measurements;

Y – distance to the defined point of the object;

f - camera focal length;

p - longitudinal parallax of the point.

The rapid development of digital technologies has led to the fact that currently only digital cameras are practically used in terrestrial photogrammetry. The introduction of digital cameras in the production of terrestrial photogrammetric surveys is determined by their advantage over traditional ones [4,5,11]. These cameras allow you to quickly obtain color images of the object under study without photo laboratory dark works, have the ability to load them into the computer's memory, transmit over significant distances and take measurements on the monitor screen. However, the existing special high-resolution digital cameras, proposed for photogrammetry, are very expensive, which complicates their application in solving the applied tasks. Therefore, in many cases it seems appropriate to use cheaper non-metric cameras. To perform terrestrial photogrammetric surveys, metric digital cameras have been created. In these cameras, as a rule, the lens and the photodetector are rigidly mounted on the camera body, ensuring the constancy of the interior orientation elements of the camera. Elements of the internal orientation of these cameras, including the parameters of photogrammetric distortion, are determined at the factory. Such cameras are available with a light-receiving matrix of up to 60 megapixels and lenses with focal lengths of the order of 35, 50, 80 and 100 mm.

At the same time, continuous improvement of the technical characteristics of amateur and professional digital shooting cameras indicates that they can also be used for photogrammetric shooting [6]. The main condition for the possibility of their use for photogrammetric shooting is to increase their accuracy. For this, they must first be subjected to a photogrammetric calibration procedure, as a result of which elements of the camera's internal orientation are determined, including photogrammetric distortion parameters of the camera's lens.

Currently, various types of non-metric professional and amateur digital cameras are used for ground-based photogrammetric shooting, depending on the required accuracy of photogrammetric determinations, the size of the subject being taken and the distance to it.

In terrestrial photogrammetry, stereophotogrammetric cameras are also used [8]. These cameras are two identical shooting cameras rigidly mounted parallel to each other on some basis, so that the optical axes of these cameras are perpendicular to the basis. As a result of

the photogrammetric calibration of stereophotogrammetric cameras, not only elements of the internal orientation of the shooting cameras are determined, but also elements of their external orientation in the predefined coordinate system of the stereophotogrammetric camera, for example, in the coordinate system of the left camera. In this case, when photogrammetric processing of images obtained by a stereophotogrammetric camera, the coordinates of the points of the photographed object can be obtained in the coordinate system of the stereophotogrammetric camera according to the direct photogrammetric notation formulas.

Photogrammetric calibration of digital survey cameras is carried out in order to determine the values of the interior orientation elements of survey cameras, including the parameters of the photogrammetric distortion of the camera lens [3, 7].

Amendments d_x and d_y to the coordinates of the points measured in the image, compensating for the influence of the photogrammetric distortion of the camera lens, are generally described by various equations. The most widely used equations of the form:

$$\begin{aligned}d_x &= x(r^2k_1 + r^4k_2 + r^6k_3) + (r^2 + 2x^2)p_1 + 2xyp_2, \\d_y &= y(r^2k_1 + r^4k_2 + r^6k_3) + (r^2 + 2y^2)p_2 + 2xyp_1,\end{aligned}\quad (6)$$

wherein: x, y — coordinates of image points;

k_1, k_2, k_3 - radial distortion coefficients;

p_1, p_2 - lens tangential distortion coefficients;

r – distance from the main point of the image to the measured point

$$r = \sqrt{(x - x_0)^2 + (y - y_0)^2};$$

x_0, y_0 - coordinates of the main point of the image.

As the practice of photogrammetric calibration of digital cameras shows, to describe photogrammetric distortion in the vast majority of cases, it suffices to restrict ourselves to the coefficients k_1, k_2 (2) of the system of equations. At present, during the photogrammetric calibration of digital non-metric cameras used in ground-based photogrammetric surveys, it is performed using images of spatial and flat test objects [8]. A more detailed discussion of the calibration of non-metric digital cameras is not considered in this paper.

Therefore, in many cases it seems appropriate to use cheaper non-metric cameras. Digital non-metric cameras are currently available from many manufacturers. The desire for their use in photogrammetry is due, on the one hand, to low cost, and, on the other, to the continuous improvement of their technical characteristics. At the same time, digital photogrammetry software is being improved, and in particular in the field of photogrammetric calibration. All these improvements make it possible to turn non-metric cameras into accurate measuring devices for solving arising applied problems. The main difference between digital photogrammetric cameras and non-metric cameras is that the internal orientation elements of non-metric cameras are not known: focal length, coordinates of the main point and lens distortion [7].

To use non-metric cameras for measuring purposes, it is necessary to make sure that it is possible to obtain the desired result at the design stage; for this, it is necessary to determine its elements of internal orientation and distortion. To determine the permanent elements of cameras, there are many ways to calibrate them. [3]. The obtained digital images allow them to be measured on a monitor screen in the presence of photogrammetric programs imitating the operation of a stereo comparator.

The most acceptable way to calibrate is to shoot an object with known coordinates. Unknown elements of the internal orientation and distortion of the lens can be determined

using a special mathematical apparatus - the calibration method during processing. To determine them, you must have at least five reference points, but in practice it is recommended to work with 8-10 points per model.

From the above it follows that the expected errors in the plane of the image are 1/3000, the errors along the Y axis are 1/1000. The accuracy of determining coordinates at distances to the berm of 150 - 200 m in most cases is sufficient to build plans of scale 1: 1000, as well as to build profiles of the earth's surface.

An a priori estimation of the accuracy of determining the coordinates of an object using formulas (5), (6) shows that the coordinates can be determined with fairly high accuracy. Table 1 shows the dependence of the accuracy of determining the coordinates of the object from the distance to the determined point. Errors along the X and Z axes can differ significantly from errors along the Y axis, this is due to the fact that the measurements on the first two axes are monocular, while the laws of stereoscopic perception come into play when measuring along the Y axis.

3 Result

An error in determining the coordinates of the points of the berm leads to an error in determining its volume m_v . Table 1 shows the data characterizing the accuracy of determining the volume from errors in determining the coordinates of the points of the berm, calculated by the formula:

$$m_v = V \sqrt{m_x^2 + m_z^2 + m_y^2} \quad (7)$$

Table 1. The data characterizing the accuracy of determining the volume from errors in determining the coordinates of the points of the berm.

Distance Y (m)	m_x, m_z (m)	m_y (m)	m_v (%)
25	0.01	0.02	2.5
50	0.02	0.04	5.0
75	0.02	0.07	7.5
100	0.03	0.09	10.0
150	0.05	0.14	15
250	0.08	0.23	25

An analysis of the data shows that the use of non-metric cameras with a resolution of 1152x864, with the number of pixels of the formed image equal to 1.02 million pixels and a focal length of 1800 pixels for stereo photogrammetric shooting will allow to determine the scope of earthworks with an error not exceeding 5% when the camera is no more than 50 m from the berm.

The assessment is not fully rigorous, since it does not take into account systematic and random errors, but generally gives an idea of the accuracy that can be expected from the use of non-metric cameras in solving applied tasks, including the determination of the scopes of earthworks at construction sites.

To increase the reliability and accuracy of determining the coordinates of the points of the berm, it is recommended to pre-mark not only the reference points, but also the ones determined in the future by photogrammetric method. High-resolution cameras of the order of 1280x960, 1280x1024 and more will help to increase the accuracy of photogrammetric definitions. The attractiveness of such cameras produced currently is in their relatively low price. Determination of volumes of transported soil using non-digital digital cameras is associated with the execution of types of work in a certain sequence, which are added to the technological scheme (Fig. 3).

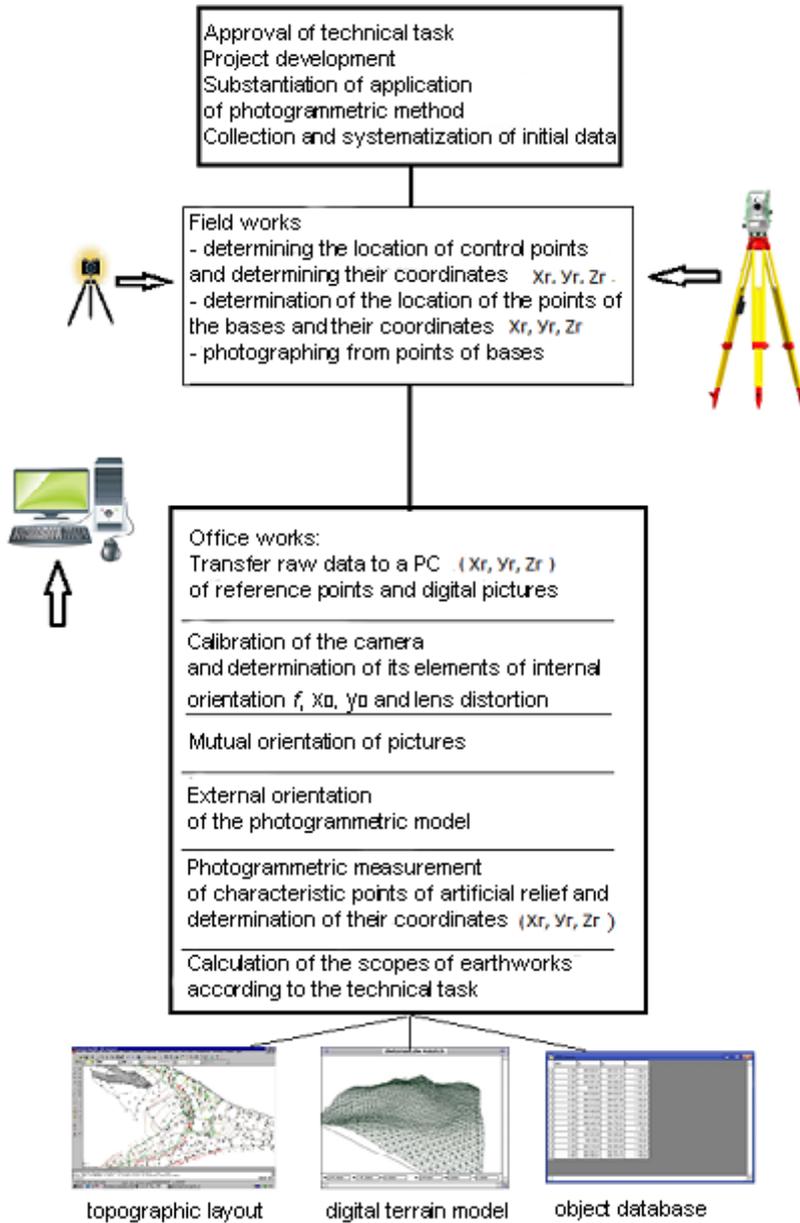


Fig. 3. Technological scheme for determining the scopes of earthworks using non-metric cameras.

To reduce the volume of field geodetic works during repeated stereo surveys, it is advisable to conduct phased surveys when, at the first stage, surveys are taken from relatively large distances and the berm fits on a small number of stereo pairs. In this case, the bases are provided with geodetic definitions of the coordinates of the ends of the bases and two or three control points on a stereo pair (Fig. 4). Photogrammetric processing of these stereopairs is based on the received geodetic data and coordinates of connecting points are determined. Repeated surveys to determine the volume of oil-contaminated soil delivered are carried out without any geodetic preparation and without measuring the lengths of the bases. Repeated surveys are processed according to the previous version, and

the connecting points with stereo pairs of the first stage serve as a geodetic reference for them.

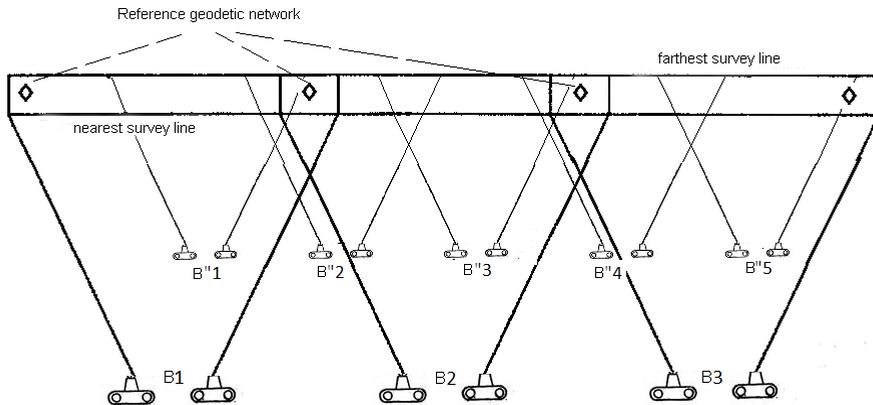


Fig. 4. The scheme of the location of the bases of photographing during the phased shooting of a site.

4 Discussion

The rapid development of digital technologies and their continuous improvement has changed the idea of solving many technical problems, including methods of terrestrial-based photogrammetry. Continuous improvement of the characteristics of digital photographs, technical means of their production and methods of photogrammetric processing in computer systems, significantly expand the capabilities of ground-based photogrammetry and open up new possibilities for digital photogrammetry.

An analysis of the functioning photogrammetric technology and technical means of obtaining digital images indicates the possibility of reducing the requirements for digital cameras provided that the method of photogrammetric calibration of digital non-metric cameras is introduced. This will allow the use of ground digital photogrammetry methods in solving many applied tasks.

5 Conclusion

The data presented in the work show the possibility of using non-metric digital cameras to solve the applied tasks of determining the scope of earthworks using the photogrammetric method. The use of digital cameras in practice allows us to reduce the time for obtaining images and completely eliminate their initial processing. The measurement of digital images on a PC instead of bulky and expensive optical-mechanical devices provides the basis for their use in many cases of applied photogrammetry. Given all of the above, the interested parties, the customer or contractor, can easily implement a photogrammetric method to determine the volume of soil movement and make sure its effectiveness, reliability, simplicity and low cost.

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