Monitoring of Mining Facilities Using Archival and Modern Aerial Photographs

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Abstract

Of great importance are the issues of studying the harmful impact of the extractive industry on the environment, on changes in the landscape of these territories, which, as a rule, are covered with new disturbed lands, polluted water bodies and air. There-fore, the conducted studies are relevant. The aim of the study is to determine the characteristics of the territories where indus-trial mining facilities are located and the features of their changes over time, using images obtained in different ways and dates. The methodology is based on the analysis and analysis of the results of experimental work from the processing of samples taken in different ways and on different dates. The analysis of the obtained data allowed us to determine the requirements for the work on processing such images. Based on the results of the study of the methodology for joint processing of surveys for 1977 and 2021, carried out in fundamentally different ways - photographic and digital, the magnitude of changes in the quarry over this period of time was determined. The obtained values of changes allow monitoring the volumes of mineral extraction and making adjustments to the plans for field development. The scientific novelty of the obtained results lies in the development and testing of a method for determining the magnitude of changes in the shape and size of a quarry over a significant period of time, through the simultaneous processing of images for different dates and obtained in different ways, since at the end of the 20th century only photographic shooting was performed, and today only digital. The analysis of the research results allowed us to conclude that it is possible to use archival aerial photography to study changes in territories. Particular attention was paid to the selection of appropriate software. The practical significance of the conducted research is in obtaining data that allows solv-ing surveying support problems related to the assessment of mineral extraction over a long period of time. Key words: digital methods, survey, camera, archival photos, collaborative processing.

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1. Introduction

Regions where minerals are extracted face the problem of preserving the environment: from excessive pollution of air, water and soil; from changes in the natural landscape and the position of water bodies; from changes in climatic conditions under the influence of production processes, etc. This is why scientists from different countries have recently been studying the harmful effects of various industrial processes on the environment and working on developing measures to protect and preserve it [1-4]. With the development of new technologies in the world, more effective methods of environmental research are emerging and finding their use in various industries [5-7]. The latest technologies also affect the efficiency of mine surveying support for mining operations, allowing them to solve problems that were previously difficult or impossible to solve [7-10]. Modern digital and satellite technologies play an important role in the automation of mine surveying work and in increasing its efficiency [11-16]. Laser scanners, electronic tacheometers, satellite systems, drones and other equipment currently used in mine surveying support for mining operations have significantly reduced the volume of routine operations that were performed daily by specialists in mine surveying departments of mining enterprises. It is known that one of the areas of automation of mine surveying work is the widespread use of remote methods for performing surveys of the earth's surface and objects. Today, these are digital aerial and ground survey methods, with the purpose of processing its results in various software tools. Special software is used to process the results of aerial and ground surveys, and the most effective one is selected depending on the purpose of the survey, the accuracy and volume of the initial data [17, 18]. To implement modern digital filming into production, powerful computers are needed, such as stationary workstations, for example, server-type, which is capable of handling large volumes of data, and portable ones for work in the field. In addition, the Internet is needed for online communication with servers and complex automated systems. Today, in the 21st century, it is difficult to imagine mine surveying without new technologies, modern devices and software, which are used at all stages of mineral deposit development.

2. Using photogrammetric methods in Kryvbas

Scientists and surveying specialists from mining companies have always worked on issues of increasing the efficiency of surveying support for mining operations (Fig. 1, Fig. 2). It is clear that at one time it was an achievement to use photographic images and devices for their processing in geodesy, geology, mining and other branches of the national economy (Fig. 3, Fig. 4). Modern digital photography has replaced photographic photography due to its high cost and inertia. However, it is worth noting that aerial photography materials taken at that time today not only have historical value, but are

Fig. 1. Drone eBee
Rys. 1. Drone eBee

Fig. 2. SenseFly Aeria X
Rys. 2. SenseFly Aeria X

Fig. 3. Airplane AH-2
Rys. 3. Airplane AH-2

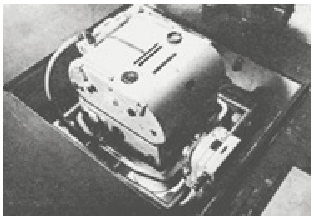

Fig. 4. AFA-100
Rys. 4. AFA-100

also a source of technical information necessary for studying the development of enterprises, territories, etc. The archives contain aerial photographs from the last century, but their use for solving technical problems is limited by a number of reasons. These limitations are related to the deformation of photographic materials and the need to digitize images so that they can be processed in standard software.

Previously, so-called "universal" stereo devices were used to process photographic images. Today, these devices, as a passed preliminary stage of photogrammetric methods of image processing, are not used due to their low efficiency.

That is, the use of archival photographs is limited by a number of technical factors associated with a fundamental change in shooting technologies and the processing of their results.

The state of the mine surveying services of the Kryvyi Rih region in the previous century was characterized by the widespread use of modern methods and devices at that time, which is explained by the fact that the Kryvyi Rih iron ore basin was and is a source of strategic raw materials. Aerial photography of mining sites was widely used in the region, carried out by a specialized photogrammetric laboratory.The photogrammetric laboratory is equipped with universal devices from the German company “Carl Zeiss Jena” – stereometrographs, used for graphical and analytical processing of airborne ground-based images. The device was used for compiling topographical maps and plans, creating spatial photo triangulation, monitoring industrial and adjacent territories.

The stereometrograph processed aerial photographs with frame sizes of 18 cm x 18 cm and 23 cm x 23 cm with tilt angles of up to 5° and obtained by cameras with focal lengths from 85 mm to 310 mm. Phototheodolite survey photographs with a standard frame size of 18 cm x 13 cm were also processed. The devices had observation systems with 7x magnification, the ratio of the model scale to the photograph scale was from 1.3 to 3, and the ratio of the map scale to the model scale was from 0.1 to 5.

The main purpose of the specialized photogrammetric laboratory was to perform work on compiling and updating mine survey plans. The laboratory's specialists performed aerial surveys and photo laboratory work, as a result of which the aerial photographs were suitable for processing on the then-current "universal" photogrammetric devices.

This method of compiling graphic material based on aerial photography was used by mine surveying services of Kryvbas mining enterprises until 2000. This method was replaced by a method in which photographs were scanned and then processed in software. With the development and implementation of digital photography, the mine surveying service has reached a modern level [19-21].

It is clear that the aerial photography technologies of the 20th century differ significantly from modern technologies using unmanned aerial vehicles (UAV) and digital cameras. Previously, when aerial photography of the territory of the shear zone from the Kolachevsky mine, it was necessary to obtain 4-5 aerial photographs that formed stereo pairs (a pair of photographs with a longitudinal overlap of approximately 60%); today, when shooting with a UAV, for example, eBee, from 1600 to 1700 are required. The increase in the number of photographs is due to the scale of the survey, which is an order of magnitude larger today. Since the study of the state of the territory over a long period of time required the use of old archival photographs, it was necessary to develop a method for their joint processing with new digital photographs.

When processing archival images using modern software for large areas, certain problems arise. This is primarily due to the fact that the processing algorithms are designed for a different type of data. During the research for photogrammetric processing of images the following software tools were used: Agisoft Metashape Professional, RealityCapture, 3DF Zephyr and PhotoModeler. The highest quality results were obtained using the Agisoft Metashape software tool. However, it was not possible to process images with a large overlap, so it was necessary to select images in such a way as to reduce it. As it turned out, such a problem is relevant only for areas with large differences in height, which include quarry areas and collapse zones.

Modern digital methods of obtaining information about mining facilities and the territories in which they are locat-

Tab.1. Surveys characteristics
Tab.1. Charakterystyka badań

Values	Shooting from July 14, 1977	Shooting from June 6, 2021
Shooting area, km^2	8,39	8,75
Number of shots, pcs.	12	3514
Shooting height, m	1300	180
Color gamut	Black and white 16 bit	RGB
Frame size (matrix), mm	180x180	25,1x16,7
Resolution, cm/pix	12 (scanned material)	6,84

Fig. 5. Photogrammetric scanner "Deltascan"
Rys. 5. Skaner fotogrametryczny "Deltascan"

Fig. 6. Epson 4990 Photo Scanner
Rys. 6. Skaner fotograficzny Epson 4990

ed are characterized by efficiency and the necessary accuracy, which allows for more effective solution of various tasks of the mine surveying service. Currently, based on the results of digital surveys, mine survey plans and other graphic documents are compiled, which are necessary for determining the volume of mining operations; for drawing up projects for the development of deposits; for research on landslides and various types of deformations of the earth's surface, buildings, structures; for solving other urgent tasks of the mine survey service of the enterprise [22-25].

3. General characteristics of archival and modern dig-ital photographs

The preserved archival aerial photographs are important documents containing information not only about the condition of mining facilities at the time of shooting, but also about the condition of the terrain and the environment. The use of these images allows for the following: research into the dynamics of the mining industry development; monitoring of the ecological state of the region over time; solving problems related to the design of mining operations, refining the volumes of mineral extraction, etc.

It is difficult to process archival and modern aerial photographs simultaneously. The complexity of the process of simultaneously processing photographs obtained by photographic and digital methods, as noted earlier, is caused by the significant difference in the methods of their receiving.

Since the methods of aerial photography and image processing have changed significantly over the past 20–30 years, which is associated with the rapid development of digital and satellite technologies, modern digital terrain models (DTM), relief models (DEM) and relief surveying plans, sections, etc. are now being built based on the results of processing modern digital images. Digital methods allow the characteristics of objects and their changes over a certain period of time to be presented in different tones and colors. Such a presentation of the results of research on the dynamics of the development of the process is not only visual, but also characterized by sufficient accuracy.

The purpose of this work is to study the possibility and develop a methodology for using archival aerial photographs to solve surveying service problems related to the analysis of the work of a mining enterprise over a period of time. In solving the problem, the quality of the available information in archival photographs and the methods and tools for combining it with information obtained from modern digital photographs were studied.

Modern methods of aerial photography of quarries are characterized by the use of small unmanned aerial vehicles that can carry a light load. Therefore, small-sized digital cameras with a focal length of up to 20 mm are used. Cameras used on full-frame drones designed for aerial photography may have a reduced-size matrix with a crop factor in cheaper models. Therefore, the quarry of one of the mining and processing plants of Kryvbas with an area of 8.75 km^2, where aerial photography is regularly carried out using such a camera, is covered with 3,514 images.

However, the resulting digital images are characterized not only by high image resolution and color, but also by corresponding geometric distortions. A large number of images, their calibration and high-precision binding allow for the effective elimination of geometric distortions of images. The fact that a large number of images are used when shooting a quarry using drones is due to the large scale of shooting from heights of 80 m to 200 m.

Until 2000, aerial photography of quarries and other mining facilities in Krivoy Rog was carried out from an AN-2 aircraft using primarily an aerial camera with a focal length of 100 mm. The optics of the aerial camera were of high quality with a distortion value of no more than 0.001 mm, but during photo lab processing, i.e. during development, washing, fixing and drying, as well as during storage, the photographs were subject to deformations that must be identified and excluded from measurements. In addition, it is necessary to examine the photographs for the presence of poor adhesion of the film to the leveling glass at the time of exposure and for the presence of the amount of image blurring due to camera movement during shooting.

At that time, mine surveying services did not have such convenient tools as satellite navigation devices, so the georeferencing of images involved a significant amount of field work. The height at which a quarry, dump, tailings dam or industrial area was photographed depended on the focal

Tab. 2. Scanner characteristics
Tab. 2. Charakterystyka skanerów Epson i Deltascan

Values	Epson 4990 Photo	«Deltascan»
Optical resolution, dpi	4200	3175
Maximum optical density, D	4.0	3.4
Minimum pixel size, μм	-	8
Geometric resolution, μм	-	1
Root mean square scanning error, μм	-	±3

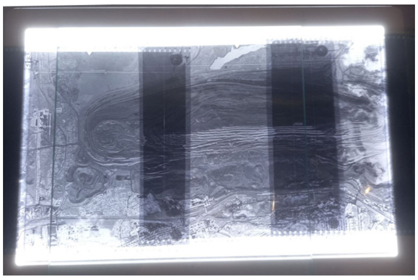

Fig. 7. Pictures of the quarry from 1977
Rys. 7. Zdjęcia kamieniołomu z 1977 r.

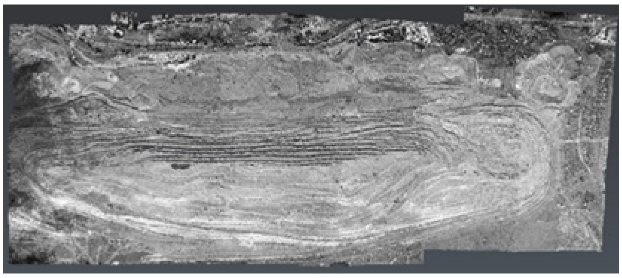

Fig. 8. Point cloud created from shoots from 1977
Rys. 8. Chmura punktów utworzona z ujęć z 1977 r.

length of the camera and the scale of the survey plan, which was compiled based on the survey materials for the relevant object and ranged from 600 m to 2000 m, respectively.

4. Collaborative processing of archival and new aerial photographs

The results of aerial photography of quarry №1 of the Central Mining and Processing Plant were selected for the research:

- 1977, scale 1:13000, 12 shoots with 90% overlap;
- 2021 at a scale of 1:10,000 in 3514 shoots with 80% overlap.

The main characteristics of these surveys are presented in Tab. 1. Since the aerial photographs from 1977 were obtained photographically, for their further use it is necessary to first digitize them, i.e. scan the photographic images. This allows them to be used later when processed in modern software. In this case, the choice of scanner is important, since not all scanners are designed to scan transparent or translucent materials, which are photographic films. There are few such scanners and they can be divided into specialized and professional ones, which are used in photo studios.

The specialized ones include the Deltascan photogrammetric scanner, which is expensive and not as common as professional ones. Professional scanners that can scan images from film with a frame size of 18 cm x 18 cm mostly belong to the premium segment and are flagship models, which also have a high cost.

In such scanners, the translucent film is placed in a special frame of the appropriate size. But it should be noted that these scanners do not provide for alignment of the frame in the plane, which is important when solving precise measuring work.

To get rid of the amount of "deformation" of the shoot into the plane, which causes deformation of the image, it is common to press the photo with matte or transparent glass.

When conducting research, a professional scanner Epson 4990 Photo was used to scan the images. This scanner was the flagship model in 2005–2006. Although the scanner is already 20 years old, its technical characteristics are still relevant today, even compared to modern models. The ability to scan large-size images (180x180 mm) with modern scanners is only available in premium flagship models (Fig. 5, Fig. 6). Table 2 shows the main characteristics of scanners of this class.

In terms of technical characteristics, the Epson 4990 Photo scanner does not compromise on the Deltascan scanner, but the rest, as a specialized premium scanner, can provide scanning accuracy. The mean-square deviation of scanning with a Deltascan scanner is ±3 μm, except when scanning archival aerial images, if the magnitude of the deformation per hour of saving (45 years) exceeds the margin of scanning, but does not give advantage to the scanner "Deltascan".

Figure 7 shows images of the quarry from 1977, used to study changes in the area from that date to 2021.

Shoots from 1977 and 2021 were processed together. Combining images from different dates allows us to assess changes in the quarry and solve the problem of determining the volume of rock mass removed during the period between the images.

Figure 8 shows a point cloud obtained from shoots taken from 1977, and Figure 9 shows a point cloud obtained from images taken in 2021.

A first, digital model were obtained separately from the 1977 shoots (Fig. 10) and separately from the 2021 shoots (Fig. 11), and then, to perform the analysis of changes and the necessary calculations, a digital model of the quarry was created based on the results of joint processing of shoots for different dates (Fig. 12).

Since modern image processing technologies allow obtaining object characteristics by displaying them in different colors, such work was carried out for the studied object [26-27]. Fig. 13 shows the fill-cut values in color, i.e., changes in the shape and relief of the quarry in the period between the dates of the surveys.

A joint processing of shoots obtained by different photographic cameras with a time interval of 11 years was also carried out. Shoots from 1995 were obtained by an aerial camera with a focal length of 100 mm, and shoots from 2006 were obtained by an aerial camera with a focal length of 152.440 mm. Shoots from different dates were used to create

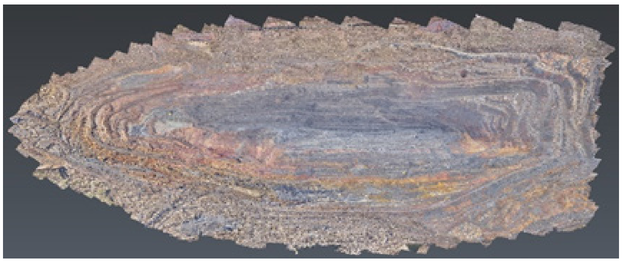

Fig. 9. Point cloud created from shoots from 2021
Rys. 9. Chmura punktów utworzona z sesji zdjęciowych z 2021 r.

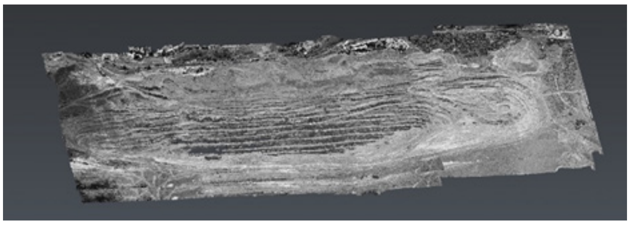

Fig. 10. Digital model from 1977 (view from the western side)
Rys. 10. Model cyfrowy z 1977 r. (widok od strony zachodniej)

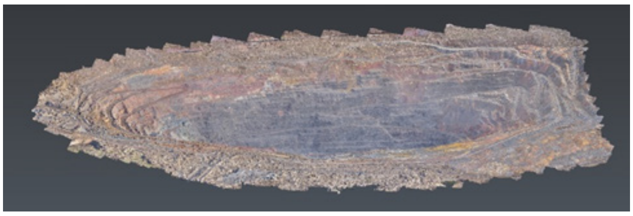

Fig. 11. Digital model from 2021 (view from the western side)
Rys. 11. Model cyfrowy z 2021 r. (widok od strony zachodniej)

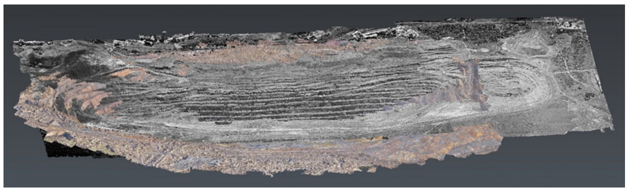

Fig. 12. Combined digital model from 1977-2021 (view from the western side)
Rys. 12. Połączony model cyfrowy z lat 1977-2021 (widok od strony zachodniej)

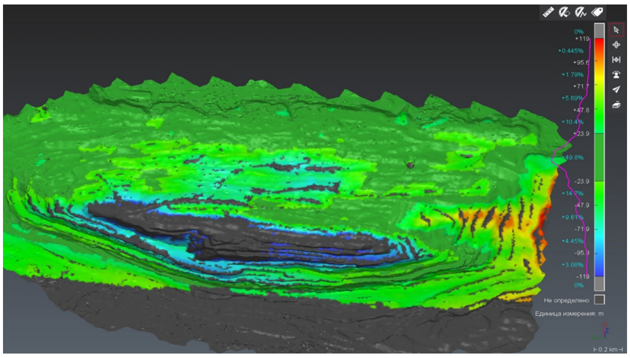

Fig. 13. Color display of relief changes
Rys. 13. Kolorowa prezentacja zmian rzeźby terenu

a stereoscopic model of quarry changes. Stereoscopic pairs of shoots were oriented to obtain a quarry model using the constant contours that had been preserved for this period. Fig. 14 shows a 3D diagram of changes over 11 years in the territory where various industrial and civil facilities are located.

Based on the results of processing images from 1995, 2006, 2020, 2021, 2022, 2023 and 2024, 6 digital models were built. These models were successively compared and combined. The resulting digital models were used to study changes in the area that had been worked by underground mining operations and to calculate the volumes of the crater at different dates.

In this area, the crater is growing larger, which confirms the continuation of the process of collapsing the rock mass and the ground's surface, caused by underground mining works. The area of the site where work was carried out to calculate the volume of the crater was 536,143.75 m^2 (53.6 ha).

The area of the contour in which the works were built with the minimum volume of the funnel amounted to 536,143.75 m^2 (≈53.6 hectares).

To carry out measurements in the selected contour limiting the collapse zone, 36 points were selected. The volume calculation was performed in Delta/Digitals software with preliminary creation of a digital relief model with a 1 m x 1 m grid. Fig. 15 shows the results of creating digital models based on images from 1995 and 2023, respectively.

The volumes of the funnel obtained from digital models (Fig. 16) were compared with the data of the mine survey service and the volumes matched.

5. Conclusion

Processing of the constructed digital models will allow to determine the volume of the extracted rock mass in the quarry for the period from 1977 to 2021 and to obtain general characteristics of the quarry development for this period. Mining operations in the quarry are carried out in the west direction, therefore the western part of the digital model is of the greatest importance. These differences are caused by the fact that in the shoots from 1977 the western part of the quarry was not yet developed. Therefore, when combining pictures for different dates of shooting, a significant difference is observed in the model at the quarry event. These differences are caused by the fact that in the pictures from 1977 the western part of the quarry had not yet been developed. Therefore, when combining pictures from different shooting dates, a significant difference is observed in the model in the western part of the quarry.

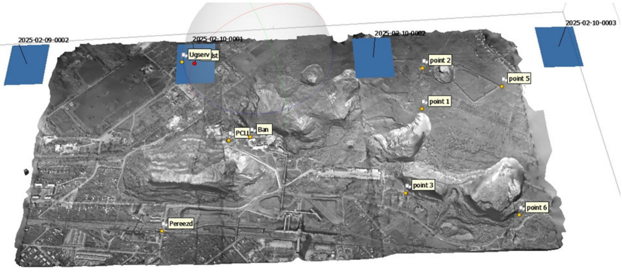

Fig. 14. 3D diagram of changes based on aerial survey results from 1995–2006
Rys. 14. Trójwymiarowy diagram zmian na podstawie wyników badań lotniczych z lat 1995–2006

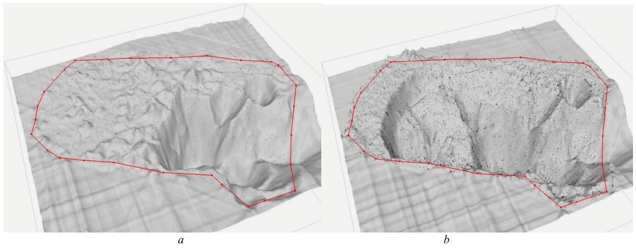

Fig. 15. Digital elevation models with a contour for calculating the volume of the crater in the collapse zone from: a – 1995; b – 2023
Rys. 15. Cyfrowe modele terenu z konturem do obliczania objętości krateru w strefie zapadliska z lat: a – 1995; b – 2023

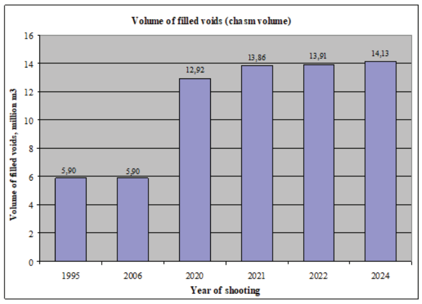

Fig. 16. Graphic representation of the volumes of voids filled
Rys. 16. Graficzne przedstawienie objętości wypełnionych pustych przestrzeni

As a result of studying the results of simultaneous processing of images for different shooting dates, one of which is archival (photographic), and the second is modern (digital). It was established that when processing archival images of photographic shooting, modern software does not work correctly in the case of significant overlap values, sometimes amounting to 90%. Therefore, for correct processing of the images in the program, the images were selected every 3. In addition, it was revealed that a significant problem when orienting images for different dates was the lack of constant contours on the working western side of the quarry, which leads to errors in orientation. This issue requires additional research and requires a solution in the future.

As proven by the conducted research, the use of joint processing of archival and new images in the study of changes in the terrain is also effective.

6. Gratitude

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Monitorowanie zakładów górniczych z wykorzystaniem archiwalnych i nowoczesnych zdjęć lotniczych

Badania szkodliwego wpływu przemysłu wydobywczego na środowisko i na zmiany w krajobrazie terytoriów pokrytych nowymi naruszonymi gruntami, zanieczyszczonymi zbiornikami wodnymi i powietrzem, są niezwykle istotne. Celem badania jest określenie cech charakterystycznych terenów, na których znajdują się przemysłowe zakłady górnicze oraz ich zmian w czasie, przy użyciu obrazów fotograficznych i cyfrowych. Metodologia opiera się na analizie wyników prac eksperymentalnych z przetwarzania próbek pobranych w różny sposób i w różnych terminach. Analiza uzyskanych danych pozwoliła określić wymagania dotyczące pracy nad przetwarzaniem takich obrazów. Na podstawie wyników badania metodyki wspólnego przetwarzania badań z lat 1977 i 2021, przeprowadzonych w sposób fotograficzny i cyfrowy, określono wielkość zmian w kamieniołomie. Uzyskane wartości zmian pozwalają na monitorowanie wielkości wydobycia kopalin i wprowadzanie korekt do planów zagospodarowania złoża. Naukowa nowość uzyskanych wyników polega na opracowaniu i przetestowaniu metody określania wielkości zmian kształtu i wielkości kamieniołomu w długim czasie, poprzez jednoczesne przetwarzanie obrazów z różnych dat i uzyskanych różnymi metodami, ponieważ pod koniec XX wieku wykonywano tylko zdjęcia fotograficzne, a dziś tylko cyfrowe. Analiza wyników badań pozwoliła stwierdzić, że możliwe jest wykorzystanie archiwalnej fotografii lotniczej do badania zmian terytorialnych. Szczególną uwagę zwrócono na dobór odpowiedniego oprogramowania. Praktyczne znaczenie przeprowadzonych badań polega na uzyskaniu danych pozwalających na rozwiązywanie problemów związanych z obsługą geodezyjną wydobycia kopalin w długim czasie.

Słowa kluczowe: *metody cyfrowe, geodezja, aparat fotograficzny, zdjęcia archiwalne, kolaboratywne przetwarzanie*