Anovar of Errors in Surveying Photogrammetric Measurements of Mountain Objects with the Help of Unmanned Aerial Vehicles

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Abstract. The application of unmanned aerial vehicle technologies in surveying is gaining pace: the results are more correct while being obtained more quickly at less amount of resources required. The drawbacks of the UAV used are most frequently detected during the flight execution and thus, a certain experience is accumulated, new methods and options for the UAV application at surface mining operations. A great part of the experimental outcomes obtained allows justifying a more efficient use of UAV from a theoretical perspective. The article considers the main problems of surveying photogrammetric measurements of the mountain objects. The authors study the impact factors influencing the errors in the measurements conducted with the help of the unmanned aerial vehicle and suggest a mathematical method for their substantiation and analysis by the example of ANOVAR of the UAV flying height and the number of control survey points that help to improve the correctness of the final model for the object measured.

1. Introduction
The application of unmanned aerial vehicles (UAV) for the surveying of mountain objects is becoming more and more frequently used tool of surveying in mining [1]. In parallel with the development of this technology the process of improving UAV use methods develops while the requirements to the precision of photogrammetric shot grow.

2. Relevance
Most specialists from the mineral extraction provision study the trend of UAV application in mining suggesting theoretical variance methods of UAV use, especially during surface mining, and proving the utility and relevance of their ideas. S.P. Bakhayeva, B.S. Aleshin, D.S. Korovin, S.N. Babaev - these are the specialists the works of who present applied interest for production engineers using photogrammetric methods of mountain object measurement.

The high quality and quantity indicators of mine surveying production with the help of modern photogrammetry define the correctness of the results of mountain objects, their volumetric and areal properties. As a result, one could obtain the accurate data of open-pit mine extraction surveying comparable with the interdepartmental ongoing volume estimates and draw a final relevant topographic plan for the deposit surface [2, 3].

Correspondingly, to reach high values of accuracy for surveying measurements, it is necessary to conduct the mathematical analysis of surveying accuracy [4] conducted with the help of UAV [4].
3. Theory

Widely speaking, mathematical processing of the surveying information is a set of calculational transformations of the initial information for obtaining the numerical values of scientific or practical value [5]. Measurement result mathematical processing has some specific features; however, using statistical methods helps to identify the genesis of main errors to a sufficient extent.

In fact, one should point to the sources of these errors [6, 7] of surveying measurements of modern photogrammetry which directly influence the final result. These factors of impact on the errors have the quantitative variability properties which also causes the complexity of their theoretical justification and definition of their interconnections and mutual influence [4].

They include natural factors: wind velocity, climate, the time of day, and artificially controlled, such as: UAV height and flight speed, forward and lateral lap of location shots, measured surface, location and number of survey control points at surveying.

Therefore, with an objective mind, to solve the problem of errors and mistakes of photogrammetry with the help of UAV [8, 9] in mathematics, it is necessary to use the ANOVAR which is convenient for the solution of mining&geometrical, displacement and other mine surveying problems [5]. In particular, at the application of two-factor ANOVAR one should check the impact of two independent variables (impact factors) on the dependent variable (survey error). One can also study the effect of interaction between two variables and the correlation of their significance [10]. Ultimately, one can make the equations of their correlation dependence. The feature variation is influenced, to a lesser or greater extent, by some or other factors. In this connection, two variances can be differentiated, a systematic and random [11].

4. Practical part, research findings

The key aforementioned impact factors as well as the tentative to analyze them with the help of ANOVAR have the generation on the basis of the UAV practical application during surface mining. As a result, one can understand which factors should be corrected to improve the efficiency of the surveying photogrammetric shot [12, 13, 14] of the mountain object with the help of the UAV technology.

Table 1. Data of final measurement errors in relation to two factors.

| Factor B (control survey points) | Factor A (flight level) |
|----------------------------------|-------------------------|
|                                  | 50 | 70 | 90 | 110 | 130 | 150 |
| -70                              | 8.0| 9.2| 11.2| 22.1| 21.2|
| -90                              | 11.| 10.9.5| 17.9| 27.0|
| 0                                | 8.1| 9.8| 12.0| 15.1| 32.0|
| 0                                | 6.2| 4.9| 8.9| 22.1| 17.9|
| 1                                | 8.2| 5.1| 6.7| 18.5| 16.0|
| 1                                | 5.8| 8.2| 6.8| 17.0| 18.9|
| 2                                | 5.0| 5.5| 5.9| 12.0| 15.4|
| 2                                | 4.2| 6.4| 8.8| 15.4| 18.0|
| 3                                | 3.6| 6.0| 6.8| 12.0| 13.7|
| 3                                | 3.6| 4.2| 5.6| 8.5| 9.0|
| 3                                | 2.0| 4.5| 7.5| 7.0| 17.1|
| 3                                | 3.1| 3.9| 6.1| 10.2| 13.9|
As an example of the ANOVAR below the authors provide the data on the final errors of the surveying photogrammetric shot in relation to the study of two factors: the flying height of the unmanned geodesic apparatus and the number of survey control points located geometrically on the surface of object measured.

The proposed empirical data further become the object of mathematical processing (ANOVAR): factor and residual variances are defined (1.1). Factor variance describes the variations of the effective feature under the influence of the studied factor; residual variance describe the variance of the effective feature conditioned by the influence of other factors [15].

\[ \sigma^2_{факт} = 114,9; \quad \sigma^2_{ост} = 4,7 \]  

With the help of the Fisher distribution, the determination coefficient is defined; it reflects the degree of impact on the error the final outcome of surveying has as differentiated from all other possible reasons (1.2):

\[ k_A = 92,0 \% \]  

As it is seen, the provided factors under study play a significant part in forming a final error of surveying measurements with the help of unmanned technology [16]. However, to evaluate the individual impact of each factor, it is necessary to continue mathematical calculations by the ANOVAR method and define the determination coefficients of each factor (1.3) as a result:

\[ k_A(factor \ A) = 63,3 \%; \quad k_A(factor \ B) = 21,4 \% \]  

legend: фактор - factor

Consequently, the error of surveying measurements is most significantly influenced by the UAV flying height. Nevertheless, the number of survey control points also has its significance which will be definitely taken into account for the formation of final conclusions on the ANOVAR made for all impact factors.

The abovementioned results of the mathematical analysis are provided in brief, and a scrupulous calculation is done to obtain them; this calculation includes obtaining of the mean, partial mean errors, squared deviations, etc.

5. Conclusions

Therefore, the nature of ANOVAR consists in the comparison of external and internal variances and forming an opinion concerning the influence and the role of the studied factor on its basis.

This extensive mathematical analysis is conducted on the basis of a large amount of empirical information which has a global nature of the theoretical justification of measurement error study [17, 18]. This entails the need of the systematization and processing of the results in such a form that will reflect the properties of the process or object under study and at the same time be convenient for the practical application [19]. Such types of tasks are optimally resolved by means of mathematical statistics methods.

In addition, statistical methods and approaches towards the resolution of various technical tasks connected to the processing and analysis of a large volume of statistic information [20], universal and are undoubtedly useful for practical application in future.

6. References

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