

Designing an improved geoacoustic event location algorithm in the "Prognoz-ADS" system

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Abstract. The article shows complex algorithm for locating geoacoustic events. Location algorithms problems are considered and methods for their solution are proposed. The requirement list is suggested for the developed algorithm, and the complex algorithm key stages are formulated.

1 Introduction

Obtaining reliable acoustic emission events coordinates is one of the main tasks of seismic-acoustic monitoring in a rock mass [1, 2]. At present, a number of algorithms and calculation methods for determining the location have been developed by the Mining Institute of the Far Eastern Branch of the Russian Academy of Sciences. Many of them have been introduced into the "Prognoz-ADS" software package and are successfully used to assess the geomechanical state of mine fields [3-5]. The developed methods are based on the analysis of the signal registration time by each of the receivers. There are also approaches based on other principles [6]. Each of the methods used has its own advantages and disadvantages. This imposes restrictions on their use. It is proposed to develop approaches for creating a universal location algorithm in the presented work, in order to use it for most receiving antennas configurations. Proven analytical methods will be applied to solve this problem. Also, some significant improvements to increase of the location accuracy and obtain additional information about the recorded signal will be used to reach this target [7].

At present, location algorithms based on the coordinate descent and brute force methods are used in most cases to determine the seismic-acoustic events coordinates [8].

The events places and empirical discrepancy value are the calculation results by each algorithm. The discrepancy allows evaluating accuracy of determining the location. There is a way to combine several algorithms in Geoacoustic-ADS program. This method consists in staged solving the determining coordinate's task using each algorithm and choosing a solution with the smallest discrepancy value.

The choice of the methods used and the setting of their parameters exist, including, for example, setting the starting point for the coordinate descent method and the grid step for the brute force method.

The constant value of the calculated speed of sound propagation in the rock mass, regardless of the signal receiver, is a disadvantage of all the algorithms used [9]. Some modifications of the presented methods allow varying this value, but only for all sensors together. This approach leads to the sound speed averaging in the rock mass. This distorts the information about the registered signal sources.

At the same time, the relative complexity of setting parameters before performing calculations is another drawback of existing methods. This imposes a number of requirements to the monitoring system operator qualification.

There are problems of wrong location determination in the case of a flat receiving antenna and the lack of an assessment of signal receiver's effectiveness in each specific case in Geoacoustic-ADS program [10].

The authors propose to formulate and develop a number of mathematical and software tools to solve these problems. These tools will lay the foundation for creating a universal complex high-precision and high-performance algorithm for determining the seismic-acoustic events location. The developed approach will provide more accurate information about signals propagation. This will serve as an additional tool for studying the geological anisotropy of rock mass.

2 Complex location algorithm designing

2.1 Complex algorithm conception

The propagation speed of acoustic waves will be different not only for each receiver, but also for one receiver along the entire signal path due to geological anisotropy and the presence of empty spaces in the researched zones [11]. Therefore, it is proposed to vary the calculated signal propagation speed for the elements of the observing network in relation to each case of signal registration. This will make it possible to obtain a velocity map and to determine the events coordinates with a higher accuracy [12]. After time, data on the velocity distribution will allow not only to increase the performance of high-precision location determination, but also to assess the rock massif state [13].

Time of signal registration varying is proposed as an alternative approach to improving the quality of determining the events location [14]. This approach will not allow getting close to obtaining real data on the longitudinal waves propagation, but can be used to assess the contribution of the observational network elements for the calculation accuracy. This will allow more efficient tuning of the initial data for performing further complex algorithm iterations.

Obtaining in accurate data on the location of the signal source is possible when using one-component sensors. Therefore, it is proposed to perform calculation with exclusion of such sensors from the receiving antenna one-by-one, if the requirement for their minimum number is confirmed. This approach and information on the geometric orientation of the receivers will allow you to get a representative about sensors efficiency and more accurately calculate the observation network sensitivity in the controlled zones [15].

The final list of proposed solutions includes:

- varying the sound speed in the rock mass for each receiver;
- calculation of the signal propagation map by recalculating the speed values after registering a new event;
- varying of the signal registration time to estimate the weight of each receiving antenna element by the contribution to the total value of the residual;
- changing the quantitative composition of the receiving antenna to assess the quality indicators of elements.

2.2 Consideration of the designed algorithm characteristics

The developed algorithm should the requirements of reliability, validity and efficiency of calculations and complies with the aspects presented in Figure 1.

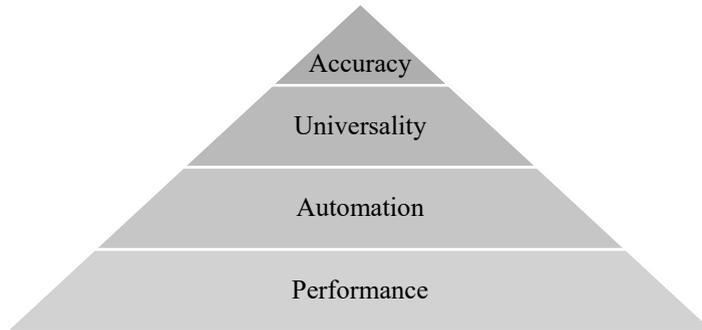


Fig. 1. Conceptual categories of the developed algorithm

Accuracy provides for obtaining a solution with a minimum discrepancy value characterizing a seismic-acoustic event close to the actual location. Achievement of the specified accuracy will be carried out using the effective selection of variable parameters, reconfiguring the receiving antenna and the order of the mathematical methods involved in the calculation.

The universality of the algorithm means the possibility of using it for the configuration of a flat antenna. It is necessary to provide for obtaining several solutions with the lowest discrepancy values to solve the flat antenna problem at the initial stage, and in the future, to obtain the most reliable position of the signal source, taking into account the orientation of the receivers in space and the calculated sensitivity zone.

Automation will reduce the work of the monitoring system operator on setting the initial parameters and on analyzing the resulting solution. It is planned to increase the degree of automation by using pilot industrial tests. The choice of a set of mathematical tools for the operation of the complex algorithm, the adjustment of the initial parameters will be carried out according to the test results. In addition, a unique methodology should be created for processing the signals recorded by the monitoring system for each controlled object [16].

Performance is characterized by the location speed decision and is associated with the qualitative assignment of the initial data and preliminary information about the location of the acoustic signal source a s ge ometric c oordinates of the p ossible l ocation z one. In addition, it is planned to implement an adaptive step of the varied parameters depending on the results obtained at each iteration to increase the efficiency of calculations.

2.3 Logical structure of the complex algorithm

Let us consider the main stages of the proposed algorithm.

Calculation of location using the brute force method and obtaining a set of coordinates of the seismic-acoustic signal source probable location.

Initialization of the current or creation of a base map of the velocity distribution and recalculation of the empirical discrepancy using available data and the signal trajectory (1).

$$S = \frac{1}{n} \cdot \sqrt{\sum_{i=1}^n (t_D - t_{Di})^2}, \quad (1)$$

where n – number of sensors that registered the event;

t_D – signal time difference (after signal registration), us;

t_{Di} – signal time difference (after calculating), us,

$$t_{Di} = \frac{d_i - d_{min}}{c} \cdot 10^6, \tag{2}$$

where d_i – distance between the well with the installed i -th sensor and the seismoacoustic event, m;

d_{min} – distance from a seismoacoustic event to the nearest sensor that registered a signal, m;

c – signal propagation speed, m/sec.

The distortion coefficient is determined for each signal receiver by varying the time of signal arrival and estimating the change in the residual value. This coefficient can take values from 0 to 1, and the total value will be 1. The receivers stack is formed according to the results of this stage, where the sensor with the highest distortion coefficient placed on the list peak.

Then the trace from the receiver with the maximum absolute signal distortion to the current location of the source is constructed and the geometric domain list is formed along the signal path. Signal propagation velocities for these domains vary and the empirical discrepancy is recalculated taking into account the velocity map. The selection of velocities continues until the discrepancy reaches a threshold critical value.

Further, the distortion coefficients are recalculated for the receivers remaining in the stack. As a result, a new linked list is formed and the selection of velocities continues along the trajectory of the next element of the receiving antenna.

The most accurate coordinates of the signal source and the parameters of this calculation are saved during for all iterations of the complex algorithm.

The solutions are derived for the case of a flat antenna to be processed by the operator. If the sensitivity zone of the controlled area is known, the solution is selected automatically.

The velocity distribution map is rebuilt as a result of analysis of obtained solutions, specifying information on the propagation of sound waves in the rock mass.

Simplified block diagram of the developed algorithm is shown in Figure 2.

The main components of the algorithm with a simplified estimate of their complexity are presented in Table 1.

Table 1. Complexity of the algorithm.

Component	Complexity
Velocity map initialization	O(n)
Locating by brute force method	O(n)
Recalculation of discrepancy	O(1)
Sensor influence calculation	O(n)
Source coordinates recalculation	O(n)
Receivers sorting (depends on an algorithm)	O(log n)

The number of receivers in comparison with the number of calculated spatial domains is much less. Therefore, regardless of the sorting algorithm used, the greatest load on the computing power will be the number of calculated domain and then brute force operation to determine event coordinates with complexity O (n).

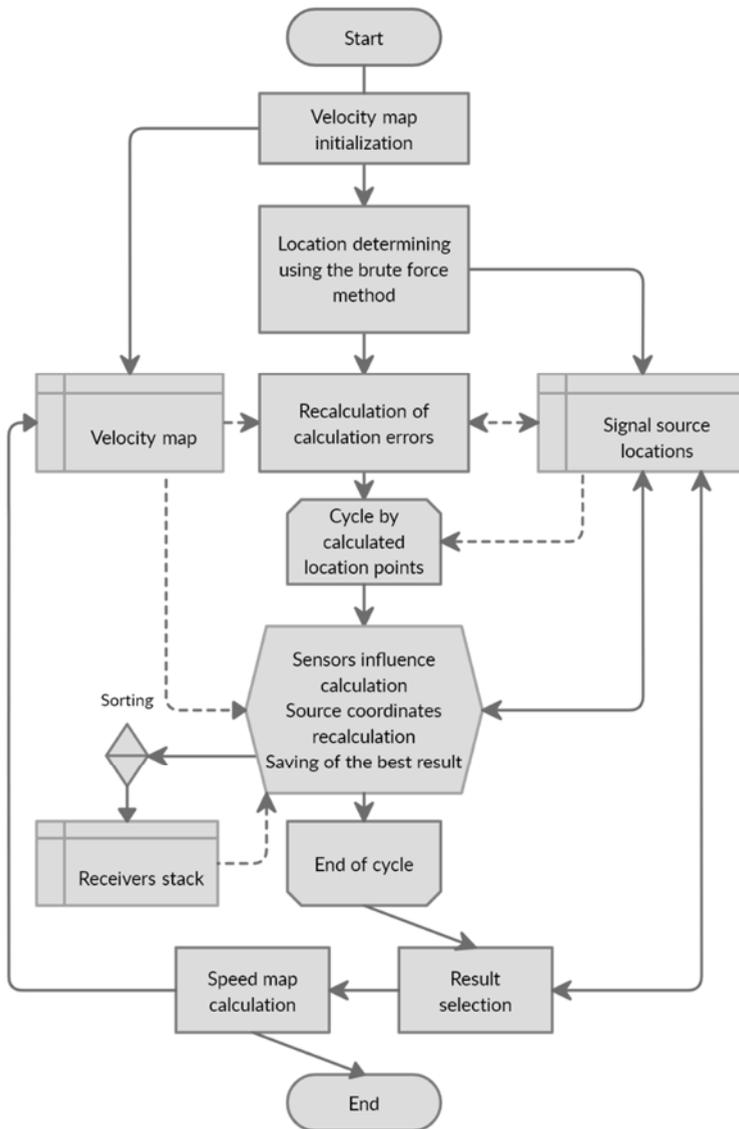


Fig. 2. A simplified block diagram of the complex algorithm

3 Conclusions

The approaches discussed in the article will solve a number of location methods problems used in the “Prognoz-ADS” system currently. A complex location algorithm will allow solving the problem of a flat receiving an antenna and obtaining information about the propagation of sound waves in a rock mass from a seismic-acoustic signal source. The proposed approaches will be achieved by meeting the requirements for precision, universality, automation and performance. The initial concept of a complex location algorithm was formulated in the presented work and the authors will carry out its implementation and further development.

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