Features of the Application of the Seismic Events Localization Algorithm for Structure Recovery of the Geophysical Model of the Environment

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***Abstract* – This paper presents an approach to the localization of underground objects using the seismic event localization algorithm. An approach to the localization of objects of a certain form is shown using the analysis of initial seismic traces and the possibility of using parallel computations.**
The results of testing the localization algorithm for point objects of a homogeneous geophysical model of the environment are presented on model seismogram. It is shown that for point objects in a two-dimensional homogeneous environment this algorithm more accurately determines the position of the object at a depth than at the axis of a group of seismic receivers.
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***Index Terms* – Geophysics, localization of underground objects, localization algorithm, seismic.**

I. INTRODUCTION

IN THE PRESENT-DAY geophysics there is the problem of solving the inverse problem of geophysics. It consists in transition from field values to model parameters. This task is related to the type of incorrect mathematical problems, because it is rather unstable and has a large number of solutions. The solution to the inverse problem of geophysics today in full form does not exist. However, many methods of solving this problem in a private form have been developed. For example, the method of complete reversal of the wave field makes it possible to determine the velocity structure of the environment, which is usually used in the search for anomalies of the environment [1]. Localization of seismic events and underground objects also refers to a particular solution of the inverse problem of geophysics, since it reduces to calculating the coordinates of the epicenters of seismic events and the geometric parameters of the object, respectively. Some environmental parameters, for example, the wave velocity, are assumed to be known. A similar approach was for localizing the source of a seismic event described in [2]. The S- and P-wave velocities were assumed to be known. The coordinates of the source of seismic events were obtained from the ratio of the difference between the arrival times of the S- and P-waves by one receiver and from the ratio of the difference in the arrival times of the P-waves to two neighboring receivers.

II. PROBLEM DEFINITION

The purpose of this paper is to investigate the application of the seismic event localization algorithm for localizing objects of the geophysical model of the environment. It is necessary to consider the specifics of the application of the seismic event localization algorithm for the localization of point objects of the geophysical model of the environment; to develop a software implementation of this algorithm; to consider the possibility of adapting the algorithm to localize objects of a certain shape.

III. THEORY

A. An Algorithm for Localization of Point Objects of the Geophysical Model of the Environment

In a simplified form we take the object of research for a point. In this case, it is necessary to take into account that the size of the object should be at least twice the wavelength of the seismic vibrator. Then, when the environment is probed with a seismic vibrator, the reflection of the generated wave from the point object at the initial instant of time will be considered the source of the seismic event. In this case, the seismic event localization algorithm can be applied to the problem by the ratio of the difference between the arrival times of the S- and P-waves by one receiver [2].

The coordinates of a point source are determined through a system of equations. The number of equations in the system *N-1* is determined by the number of recorders, where *N* is the number of receivers.

The distance from the *i*-th receiver to the point object is determined by the formula:

$$L_i = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2} ,$$

where x_i, y_i, z_i are the coordinates of the *i*-th receiver, *x*, *y*, *z* are the coordinates of the object.

The difference between the arrival times of S- and P-waves per receiver is obtained from the relation:

$$T_{Si} - T_{Pi} = L_i \cdot \left(\frac{1}{V_S} - \frac{1}{V_P} \right),$$

where V_S и V_P are S- and P-wave velocities, respectively. The arrival times are obtained from the initial seismograms, using various signal processing algorithms. Some of them are considered in [3,4]. The choice of the algorithm is

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determined by the type of the problem being solved, the type of seismograms received, and etc.

B. The Transition from the Localization Algorithm for Point Objects to the Localization Algorithm for Objects of Different Shapes

In order to take into account the shape of the object, each point of the object is represented as the source of the seismic event. Then it is necessary to superimpose the grid on the entire investigated area of the environment and check each grid node for the presence of a signal about the seismic event on each recorder at a certain time.

Identification of the object's point as a source of the seismic event is as follows. All seismic trace is divided into windows of the same length. The size of the window is selected based on the requirements for the accuracy of the object definition. If in a single window there is a wave with amplitude exceeding the total noise level by a certain amount or more (the value of this quantity is set based on the type of the received seismic trace), then the possibility of a seismic event is fixed in this window. Further, the presence of this seismic event is verified on the remaining seismic traces corresponding to other receivers. In the case of a complete coincidence of the presence of a signal about a seismic event on all receivers, it can be argued with a high degree of probability that there is a seismic event in this computational node. By checking in this way every window in all seismic traces for the presence of a seismic event, we get a picture from the points of the object, i.e. we obtain an object of a certain form.

Calculations in each window of a single seismic trace are independent of each other, so a parallel approach can be applied to this problem.

To implement the parallel approach two technologies will be considered: OpenMP + MPI and CUDA + MPI with schemes similar to those in [5]. In both cases, the design area is divided into layers along the direction of one of the coordinate axes. All information exchange is performed using MPI technology.

IV. Experimental Results

The algorithm for localization of point objects of the geophysical model of the environment was implemented in C ++. A homogeneous two-dimensional environment with known waves velocities was defined: V_S = 1.4 km/s и V_P = 2 km/s. The coordinates of the receivers were also given (see Table I). Point objects were investigated. In the first case, the object was at a depth (along the *Oy* axis) 8 km perpendicular to the Earth's surface and 8 km from the seismic vibrator (along the *Ox* axis). In the second case, the object was in the same position in width and 80 km in depth from the Earth's surface. According to model seismograms, in both cases, the arrival times of S- and P-waves for each receiver were determined (see Tables I and II).

TABLE I

Calculation Of The Coordinates Of A Point Object. The Real Position Of The Object Corresponds To 8 Km In Width And 8 Km In Depth

	receiver №1	receiver №2	receiver №3
coordinates of the *i*-th receiver, $x_i;y_i$ [km]	5;0	9;0	13;0
S-wave arrival times with an error of no more than 0.001 s, T_{Si} [s]	6.1038	5.758	6.7385
P-wave arrival times with an error of no more than 0.001 s, T_{Pi} [s]	4.271	4.032	4.716
calculated object coordinates: $x_0\pm \Delta x_0$ [km] $y_0\pm \Delta y_0$ [km]	8.0±0.6 8±0.001		
S-wave arrival times with an error of no more than 0.01 s, T_{Si} [s]	6.093	5.765	6.749
P-wave arrival times with an error of no more than 0.01 s, T_{Pi} [s]	4.277	4.021	4.708
calculated object coordinates: $x_0\pm \Delta x_0$ [km] $y_0\pm \Delta y_0$ [km]	8.0±0.24 8±0.04		

TABLE II

Calculation Of The Coordinates Of A Point Object. The Real Position Of The Object Corresponds To 8 Km In Width And 80 Km In Depth

	receiver №1	receiver №2	receiver №3
coordinates of the *i*-th receiver, $x_i;y_i$ [km]	5;0	9;0	13;0
S-wave arrival times with an error of no more than 0.001 s, T_{Si} [s]	57.184	57.146	57.2534
P-wave arrival times with an error of no more than 0.001 s, T_{Pi} [s]	40.0272	40.004	40.079
calculated object coordinates: $x_0\pm \Delta x_0$ [km] $y_0\pm \Delta y_0$ [km]	8.0±0.4 80±0.001		
S-wave arrival times with an error of no more than 0.01 s, T_{Si} [s]	57.173	57.157	57.244
P-wave arrival times with an error of no more than 0.01 s, T_{Pi} [s]	40.038	39.995	40.088
calculated object coordinates: $x_0\pm \Delta x_0$ [km] $y_0\pm \Delta y_0$ [km]	8.0±3.56 80±0.04		

V. Discussion of Results

It can be seen from the results that this algorithm is sensitive to the error in determining the time of arrival of waves on the receiver. So, the algorithm with the same accuracy determines the depth of the object for both 8 and 80 km. In both cases, with the contribution of the error in determining the arrival times of waves on the receivers to 0.01 seconds, the error in calculating the depth of the object is up to 1 meter. However, this algorithm rather fuzzy determines the position of the object relative to the axis of a group of receivers. So, with the contribution of the error in determining the arrival times of waves on receivers to 0.001 s, the error in calculating the position of the object along the *Ox* axis reaches up to 1 meter, and with an error in the determination of T_{Si} and T_{Pi} to 0.01 seconds for a deep object, the error in determining the coordinate of the object reaches up to 3.6 km.

VI. Conclusion

This paper shows that for the problem of localizing objects of the geophysical model of the environment, one can adapt the seismic event localization algorithm based on the difference in the arrival of S- and P-waves per receiver. An approach is proposed for determining objects of a certain form using the analysis of initial seismic traces and the possibility of using parallel computations. It is shown that the used algorithm determines the position of point objects in a two-dimensional homogeneous environment at different depths with the same accuracy. It is noted that the position of the object along the axis of the group of receivers is more sensitive to the accuracy of the determination of T_{Si} and T_{Pi} and requires the contribution of the measurement error of these values not more than 1 microsecond.

VII. Further Development

In the future it is planned to investigate this algorithm for point objects in a heterogeneous environment (for example, a layered structure). Next, proceed to objects of a certain form in a homogeneous, then heterogeneous environment, and apply a parallel approach to this problem.

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