APPLICATION OF BOINC-BASED VOLUNTEER COMPUTING FOR COMPARISON OF THE GEOACOUSTIC INVERSION ALGORITHMS EFFICIENCY

O.S. Zaikin [1,2,a], P.S. Petrov [3,4], I.I. Kurochkin [5]

[1] *ITMO University, 49 Kronverkskiy prospekt, Saint Petersburg, 197101, Russia*

[2] *Matrosov Institute for System Dynsmics and Control Theory SB RAS, 134 Lermontov street, Irkutsk, 664033, Russia*

[3] *V.I. Il'ichev Pacific Oceanological Institute FEB RAS, Far Eastern Federal University, 43 Baltiyskaya street, Vladivostok, 690041, Russia*

[4] *Far Eastern Federal University, 8 Sukhanova street, Vladivostok, 690090, Russia*

[5] *A.A. Kharkevich Institute for Information Transmission Problems RAS, 19 build 1 Bolshoy Karetny pereulok, Moscow, 127051, Russia*

E-mail: [a] zaikin.icc@gmail.com

The BOINC-based volunteer computing project Acoustics@home was employed to study the accuracy of the sound speed profile reconstruction in a shallow-water waveguide using a dispersion-based geoacoustic inversion scheme. This problem was transformed into a problem of black-box minimization of a certain mismatch function. According to the first approach, a sound speed profile is considered a piecewise-linear function with fixed uniformly-spaced nodes. At these nodes the values of sound speed are obtained in the course of inversion. In the second approach the depths of the sound speed profile nodes are also considered inversion parameters, however their number must be smaller than in the first approach due to the computational complexity limitation. Several large-scale computational experiments reveal that for the considered problem the second approach leads to a more accurate sound speed profile estimation.

Keywords: volunteer computing, BOINC, geoacoustic inversion, underwater acoustics, black-box optimization

1. Acoustics@home

Volunteer computing [1] is a type of distributed computing, that is based on the usage of resources donated by private persons via the Internet. Volunteer computing suits well to solve computationally hard problems, which can be decomposed into a set of independent subproblems. In last two decades, several important results in various scientific areas (astronomy, medicine, mathematics, etc.) were obtained in volunteer computing projects. The most popular platform for organizing volunteer computing projects is BOINC (Berkeley Open Infrastructure for Network Computing) [2].

In March 2017, the BOINC-based volunteer computing project Acoustics@home was launched [3]. It is the first volunteer computing project aimed at solving computationally hard problems in underwater acoustics. The project software is based on the MPI-program CAMBALA [4], that is designed for launching on computing clusters.

Acoustics@home has several daemons, launched on the project's server. Work generator decomposes an original problem into independent subproblems by varying several considered parameters. The rest parameters are varied in the computing application of the project which is launched on volunteers' computers.

Since its launch, the project has been used for solving hard inversion problems. In particular, sound speed profile reconstruction in a shallow-water waveguide was performed. For this purpose, a dispersion-based geoacoustic inversion scheme was employed. This scheme is briefly described in the next section.

2. Geoacoustic inversion as a black-box optimization problem

The study of ocean bottom is required for mining, while the study of its water columns can be used for underwater navigation and tracking of large sea animals. Using geoacoustic inversion, water column and bottom parameters can be reconstructed from acoustic data [5]. Usually the data for the geoacoustic inversion is mostly obtained using expensive receiver arrays.

Recently it was shown that a broadband pulse signal recorded by a cheap single hydrophone can be also successfully used for estimating the acoustical parameters of sea bottom (see, e.g., [6]). The inversion procedure in this case relies on the dependence of arrival times on frequency and mode number (see details, e.g., in [6, 7]).

The implementation of this method in practice can be reduced to a black-box minimization problem, in which an objective function should be minimized in a discrete search space [3, 4], and every evaluation of this function requires numerous solutions of an acoustic spectral problem [4, 7]. Thus, the corresponding search space can be easily divided into a large number of relatively simple independent tasks, which can be processed in parallel.

3. Computational experiments

In 2017, in Acoustics@home the problem of estimation of the sound speed profile in a water column was considered. This problem is described in [3] in detail. A sound speed profile was considered a piecewise-linear function with fixed uniformly-spaced nodes. The more nodes one can afford, the better is the possible accuracy of the estimation based on the dispersion-based geoacoustic inversion algorithm. In the first experiment, values of five nodes were varied. Each node had 31 possible sound speed values (from 1450 m/s to 1510 m/s with the step of 2 m/s), so the search space contained 28 629 151 points. A brute-force algorithm was employed to calculate a value of the objective function in each point of the search space. In each such point the corresponding direct problem can be solved in few seconds on 1 CPU core. The search space was divided into 29 791 workunits, which were made by varying values of the first three nodes. Acoustics@home client application had to vary values of other two nodes for each workunit, so 961 points had to be processed within it. On average it took about 1 hour to process one such workunit on 1 CPU core. This experiment was completed within 10 days. The best value of the objective function was 0.00428371. In the second experiment, values of six nodes were varied. The search space was divided into 923 521 workunits (by varying the values of the first four nodes), each of them consisted of 961 points. This experiment took 58 days. The best value of the objective function was 0.00384831. In the considered experiments the project's performance was comparable to that of a computational cluster equipped with 500 modern CPU cores.

In 2018 two more experiments were held to solve the same inversion problem. In these experiments, the depths of the sound speed profile nodes were also considered inversion parameters. In the third experiment, three sound speed profile nodes were considered. The depth of the first node is constant (it corresponds to the water surface, i.e. it has the depth 0 m), while the depths of other nodes were varied from 2 to 40 meters with the step 1 meter. In total, there were 666 possible combinations of depths values. Values of all three nodes were varied too. While each of three nodes had 36 possible values (from 1440 m/s to 1510 m/s with the step of 2 m/s), the search space contained 31 072 896 points (5 parameters were varied in total). 23 976 workunits were generated and processed within 12 days. As a result, the minimum of the objective function 0.003945 was found: The corresponding point is: 23 m, 33 m, 1506 m/s, 1490 m/s, 1462 m/s.

In the fourth experiment, four nodes were considered. Depths of three nodes were varied with the same bounds and step as in the third experiment. In total, 7 140 possible combinations of depths values were constructed. While each node had 36 possible values, the search space contained 11 992 458 240 points (7 parameters were varied in total). The experiment was launched in April 2018 and is still running; 52 % of the search space has been processed within 6 months. The current minimum of the objective function is 0.003784. The corresponding point is: 23 m, 34 m, 40 m, 1506 m/s, 1490 m/s, 1454 m/s, 1466 m/s. It should be noted, that this value of the objective function is the best one for the considered problem found so far.

4. Acknowledgement

This study was partially supported by the Council for Grants of the President of the Russian Federation (grant No. MK-2262.2017.5) and the Russian Foundation for Basic research (grants No. 16-07-00155-a, No. 18-29-03264-mk and No. 18-57-06003-Az-a). The authors thank all Acoustics@home volunteers, whose computers took part in the experiments.

5. Conclusion

Several large-scale computational experiments were held in Acoustics@home. It was revealed, that for the considered problem the approach, in which the depths of the sound speed profile nodes are also considered inversion parameters, leads to a more accurate sound speed profile estimation.

References

[1] Holohan A. Community, Competition and Citizen Science: Voluntary Distributed Computing in a Globalized World. Global Connections. Taylor & Francis. 2016.

[2] Anderson D.P. BOINC: a system for public-resource computing and storage // Proceedings of the 5th IEEE/ACM International Workshop on Grid Computing, GRID'04. Washington, DC, USA, 2004. IEEE Computer Society. pp. 4-10.

[3] Zaikin O.S., Petrov P.S, Posypkin M.A., Bulavintsev V.G., Kurochkin I.I. A volunteer computing project for solving geoacoustic inversion problems // Open Engineering. 2017. Volume 7, Issue 1. pp. 363-370.

[4] Zaikin O.S., Petrov P.S. Algorithm of reconstruction of the sound speed profile in a shallow-water geoacoustic waveguide from modal dispersion data // Optoelectronics Instrumentation and Data Processing. Vol. 52, Issue 3. pp. 259-265.

[5] Jensen F.B., Kuperman W.A., Porter M.B., Schmidt H. Computational ocean acoustics. Springer, New-York et al. 2011.

[6] Bonnel J., Chapman N.R. Geoacoustic inversion in a dispersive waveguide using warping operators // The Journal of the Acoustical Society of America, 130(2):EL101–EL107. 2011.

[7] Petrov P.S. A method for single-hydrophone geoacoustic inversion based on the modal group velocities estimation: Application to a waveguide with inhomogeneous bottom relief // Proceedings of the International Conference Days on Diffraction. 2014. pp. 186–191.