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MODELING THE ACOUSTIC FIELD BASED ON SOUND DISPERERSION DURING REFLECTIONS OF WAVE TRACING IN OPEN AREAS

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Abstract. A method of numerical modeling of acoustic fields in open areas with the possibility of parallelization of calculations is proposed. This method is part of a developed software solution that allows you to perform physical field modeling in various subject areas, being scalable in the sense of using an arbitrary set of parallel calculators. The use of existing modeling systems is associated with great difficulties in solving complex problems with a high degree of detail of the simulated object. Greater accuracy implies a high degree of discretization, a greater number of elementary model calculations performed. Parallel and distributed computing systems have a much better ratio of accuracy-approximation and time and cost costs compared to single-processor systems. Modern general purpose modeling systems use a simplified ray model of sound propagation, which neglects diffractional and interference effects, which are often critical in industrial acoustics. The article proposed a method based on the approximation of the principle of superposition of sound fields. It is accurate, while the linearity of the equations of acoustics is relevant. The basis is the Rayleigh integral and the approximation of reflective surfaces by flat point radiators. A parallel form of such a method is presented, as well as an analysis of its properties, both in sequential and parallel forms.

Key words: parallel calculations, computer modeling, industrial acoustics, Rayleigh integral, software complex, high performance computing

МОДЕЛЮВАННЯ АКУСТИЧНОГО ПОЛЯ НА ОСНОВІ ДИСПЕРСІЇ ЗВУКУ ПРИ ВІДБИТТІ ТРАСУЮЧИХ ХВИЛЬ НА ВІДКРИТИХ МАЙДАНЧИКАХ

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Анотація. Запропоновано метод чисельного моделювання акустичних полів на відкритих майданчиках з можливістю розпаралелювання обчислень. Даний метод є частиною розробленого програмного рішення, яке дозволяє виконувати моделювання фізичних полів в різних предметних областях, будучи масштабованим в сенсі використання довільного набору паралельних обчислювачів. Використання існуючих систем моделювання пов'язано з великими труднощами при вирішенні складних завдань з високим ступенем деталізації модельованого об'єкта. Велика точність має на увазі високу ступінь дискретизації, більшу кількість виконуваних елементарних модельних обчислень. Паралельні та розподілені обчислювальні системи мають набагато краще співвідношення точності наближення та часових та фінансових витрат порівняно з однопроцесорними системами. Сучасні системи моделювання загального призначення використовують спрощену променеву модель поширення звуку, яка нехтує ефектами дифракції та інтерференції, які часто мають вирішальне значення в промисловій акустиці.

У статті запропоновано метод, заснований на апроксимації принципу суперпозиції звукових полів. Він точний, при цьому актуальна лінійність рівнянь акустики. В основі лежить Інтеграл Релея і апроксимація поверхонь, що відбивають плоскими точковими випромінювачами. Представлена паралельна форма такого методу, а також аналіз його властивостей, як в послідовній, так і в паралельній формах.

Ключові слова: паралельні обчислення, комп'ютерне моделювання, промислова акустика, Інтеграл Релея, програмний комплекс, високопродуктивні обчислення.

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1 INTRODUCTION

When using computer modeling methods, the adequacy of the model is determined by the number of elementary model calculations performed that make up the experiment, by the number of approximating discrete components. At the same time, the time and cost costs associated with conducting a model experiment increase. The time and spatial cost functions depend on the model specification. Model calculations with high requirements for the accuracy of the results require high computing power, which is provided by computers . Another problem is the narrowness of the problems solved by the modeling system and the high cost of conducting complex studies in subject areas. Existing simulation systems do not adapt well to different classes of simulation tasks. An example is the ScilabFE package Scilab, which has a computing core to which plug-ins are connected that are intended to solve certain model tasks. Another approach is to integrate heterogeneous simulation systems that implement adjustable external system interfaces. The cost of such a composition will be high. When implementing complex computer simulation systems, the problem of high complexity can be circumvented. restrictions are introduced for the tasks to be solved: the use of simplified external conditions, strict restrictions on the set of permissible input parameter values; a task with low complexity of the physical process model. Today, there are no powerful simulation systems that offer scalability to heterogeneous parallel computers. There are conceptual approaches: parallel modeling of discrete events. There are also professional solutions that implement these approaches. High-performance software and hardware solutions are not portable and are implemented with close ties to model-specific tasks, mechanized systems and compilers. Therefore, most often they are created for a specific use in a particular production activity .The aim of this study is to propose a model for the distribution of sound in open space, which makes it possible to take into account the scattering of sound during reflections with the required accuracy. A conceptualization of the algorithm based on this model with scalable calculations has been proposed.

2 LITERATURE REVIEW

Despite the large number of proposals, mathematical models reflecting the structural and functional organization of the systems under study are widely used, built on the basis of queuing theory models, the analysis of which can be carried out by analytical, numerical and statistical methods. Probabilistic methods of queuing theory are used as analytical methods, methods of the theory of Markov random processes are used as numerical methods, and simulation methods are used as statistical methods.

In [1], the author proposed a systematization of methods for analyzing experimental data based on the theory of queuing, the theory of Markov random processes, and simulation modeling methods. Methods of optimization of highly parallel computations without specifying a block diagram are considered in the first approximation.

General concepts and concepts from the field of distributed computing are considered in [2]. Methods and algorithms for solving the most important tasks are given for the asynchronous distributed systems model. Attention is paid to the logic clock mechanism, which makes it possible to significantly simplify the development of algorithms for distributed systems. The main distributed algorithms of mutual exclusion are considered to ensure the security properties and survivability of distributed algorithms. Account performance issues are not affected.

In [3], an algorithm for numerical simulation of acoustic fields in a room with the possibility of parallelization of calculations is proposed. This algorithm is part of a software solution being developed that allows modeling of physical fields in various subject areas, being scalable in the direction of an arbitrary set of parallel calculators. The use of a modeling system is associated with great difficulties in solving complex problems with a high degree of detail of the simulated object. High accuracy implies a high degree of sampling and the calculation of open acoustic fields is not provided.

In [4] Requirements-based testing is emphasized in acoustic certification documents because this strategy has been found to be the most effective at revealing errors. This paper describes the unified requirements-based approach to the creation of conformance test acoustic for mission-critical systems. The approach uses formal machine-readable specifications of requirements and finite state machine model for test sequences generation on-the-fly. Possible application of the presented approach to various areas of acoustic embedded systems testing is discussed. Only for close barrier interior clearly.

This [6] article is about of intended to serve as an introduction on modeling room geometries in software, to the facilities in the software and to the calculation principles applied in software. It will not cover in depth all facilities included in the software; explanations of displays, calculation parameters, results, etc. are available as context sensitive help from within the software applications . Only for acoustic fields with close modeling source.

This [10] article is about of intended to serve as an introduction on modeling room geometries in software, to the facilities in the software and to the calculation principles applied in software. It will not cover in depth all facilities included in the software; explanations of displays, calculation parameters, results, etc. are available as context sensitive help from within the software applications . Only for vibrations process with close modeling source.

It can be concluded that today there are no high-performance general-purpose modeling systems that provide scalability to heterogeneous parallel computers.

3 PURPOSE AND OBJECTIVES OF THE RESEARCH

In this paper, a mathematical simulation of sound propagation in an open space has been carried out, which would allow taking into account sound scattering during reflections with the necessary accuracy. Thus, it is possible to create a database of preferred operating modes and experimentally refine the mathematical model point-by-point.

To achieve the goal of the work, it is necessary to solve the following tasks:

1. To propose a conceptualization of the algorithm taking into account the requirements of scalability of calculations.

2. Consider the applicability of an arbitrary number of parallel calculators with a proportional reduction in the time spent on execution.

3. Determine the shape of the acoustic field simulation, determine the number of acoustic rays acting in the active and reactive phases, and the magnitude of the total reflected sound beam.

5. Develop a block diagram of the algorithm for calculating the geometric similarity of the sound field using an acoustic camera.

6. To test the block diagram of the algorithm for calculating the geometric similarity of the sound field in a pilot environment using a quadcopter.

4 RESEARCH RESULTS

Most modern software systems that simulate acoustic fields use a simplified radial model of sound propagation. In this model, one fall the common beam produces one reflected light. This model performs well over long distances in the far zone of the source or

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at high frequencies, when geometrical is permissible when proximity. However, in limited open spaces at low and medium frequencies, the wave effects are too large to ignore.

The basis of the presented model is the method of Rayleigh calculation of flat emitters.

Rayleigh integral has the following form [10]:

$$\boldsymbol{\varphi}(M)=\frac{1}{2\boldsymbol{\pi}}\iint_{\sigma}\frac{\partial\boldsymbol{\varphi}_1}{\partial n}\cdot\frac{e^{-ikr_2}}{r_2}\,d\boldsymbol{\sigma}, \tag{1}$$

where: $\frac{\partial\boldsymbol{\varphi}_1}{\partial n}$ – the normal component of the oscillatory velocity; r_2 – the distance to the observation point M; σ – surface of the ground on which the integration is carried out; $d\boldsymbol{\sigma}$ – elementary platform.

Integral the expression in (1) is a classical point formula source. Thus, the Rayleigh method is a discretization of the radiator into infinitely small elements — point sources and the subsequent addition of their fields at the calculated point of space.

Let us now consider not the radiation of sound by a single emitter, where (∂φ1) / ∂n is constant over the entire surface of the mechanized means, but the re-reflection (Fig. 1). The front of the emitted wave leads non-simultaneously to the same-height areas of the over-isobar surfaces. There is a phase shift of the normal component of the velocity of different elements dσ.

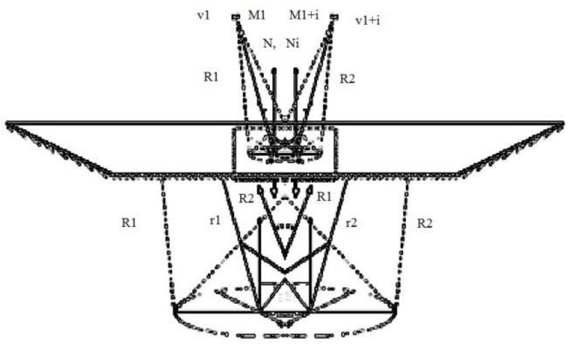

Fig. 1. Model of reflection of sound from the dirt canvas

As a primary source, take a point source with a unit amplitude.

The field of its radiation is described by the formula:

$$\varphi_1=\frac{e^{-i(\omega\tau-kr_2)}}{r_1} \tag{2}$$

where, r_1 – the distance to the reflecting surface.

Differentiating (2) by n:

$$\frac{\partial\varphi_1}{\partial n}=(grad\varphi_1,n)=-ik\frac{e^{-i(\omega\tau-kr_1)}}{r_1}\cos(r_1,n), \tag{3}$$

To calculate the distances, we use the cosine theorem (Fig. 2):

$$r^2=R^2+\rho^2-2\cdot R\cdot\rho\cdot\cos(\gamma), \tag{4}$$

where, $\cos\gamma=\sin\theta\cdot\cos\varphi$, $\rho=\sqrt{x^2}+y^2$

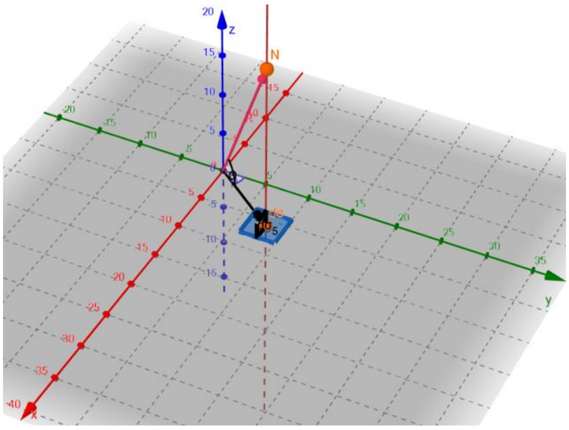

Fig 2. To the calculation of geometric similarity

From (4) we obtain:

$$r^1 = \sqrt{R^2 + \rho^2 - 2 \cdot R \cdot \rho \cdot \sin\theta \cdot cos\,(\varphi - 1/\tan(\frac{y}{x}))}, \quad (5)$$

$$\cos(r_i, n) = \cos(\pi - \theta_1), \quad (6)$$

Substituting (3), (5) and (6) into (1) we obtain:

$$\varphi(\mathrm{M}) = \frac{-ik}{2\pi} \iint_{\sigma}^{N} v \cdot \frac{e^{i\left(\omega\tau - k\sqrt{R_1^2+\rho^2-2\cdot R_1\cdot\rho\cdot\sin\theta_1\cdot\cos\left(\varphi_1-1/\tan(\frac{y}{x})\right)}\right)}}{\sqrt{R_1^2 + \rho^2 - 2\cdot R_1\cdot\rho\cdot\sin\theta_1\cdot\cos\left(\varphi_1 - \frac{1}{\tan}(\frac{y}{x})\right)}}$$

$$\frac{e^{-ik\left(\omega\tau - k\sqrt{R_2^2+\rho^2-2\cdot R_2\cdot\rho\cdot\sin\theta_2\cdot cos\,(\varphi_2-1/\tan(\frac{y}{x})}\right)}}{\sqrt{R_2^2+\rho^2-2\cdot R_2\cdot\rho\cdot\sin\theta_2\cdot cos\,(\varphi_2 - 1/\tan\,(\frac{y}{x}))}}\, dxdy, \quad (7)$$

Thus, an analytical dependence of the velocity potentials on the reflection angles is obtained. θ_1, φ_1 and distances to quadcopter reference platform positioning R_1, viewing angles θ_2, φ_2 and distances to quadcopter on positioning work platforms R_2, the shape and size of the radiation source of the audio signal. The reflection coefficient *v* is generally a complex value:

$$v = \frac{Z_2 - Z_1}{Z_2 + Z_1}, \quad (8)$$

where Z_1 , Z_2 - acoustic impedances of gaseous and solid media.

$$Z = R + i \cdot X\,, \quad (9)$$

where, R and X – respectively active and reactive acoustic impedances. However, if we consider a small element σ, then the spherical wave it radiates up to the source λ (Fig. 1) can be approximated approximately by a plane wave. Thus, the radiation resistance will be purely active [9].

This approximation is the more accurate, the smaller the element σ and the farther it is from the source. Then:

$$v = \frac{\rho_2\cdot c_2 - \rho_1\cdot c_1}{\rho_2\cdot c_2 + \rho_1\cdot c_1}, \quad (10)$$

where, ρ - the density of the medium; c - the speed of sound in the medium.

To test the adequacy of formula (7), a sound field was simulated in the COMSOL Acoustic environment. The model of a virtual experiment is shown in Fig. 3. The model includes the source, the reflecting plate Ref and the output plane of the result Reg. The reflector size is 2x2 m, the registration plane is 40x40 m. The distance between Reg and Ref is 14 m. The coordinates of the isotropic source are: x = 2 m, y = 2 m, 2 = 2 m. The simulation was performed at a frequency of 1000 Hz.

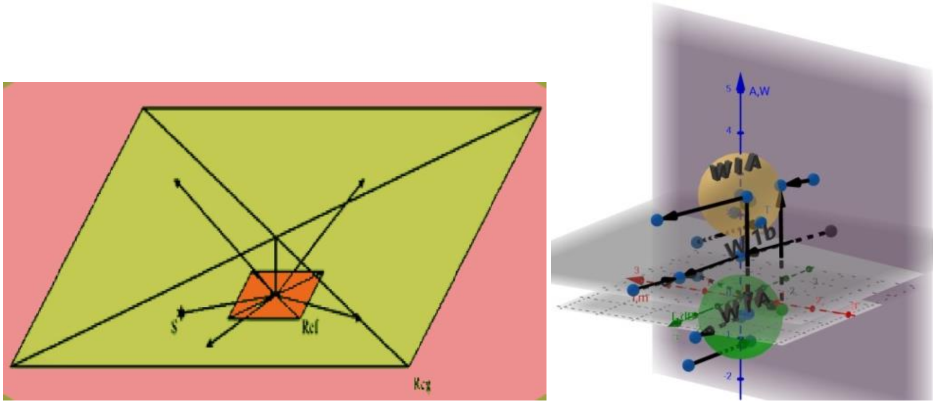

Fig. 3. COMSOL Acoustic virtual experiment model

The simulation results are shown in Fig. 4, from which it follows that the intensity maximum is in the coordinates x = -4, y = -4, which fully satisfies the geometrical acoustics. However, it is obvious that the maximum is distributed over a fairly large area, which indicates the wave nature of reflection. Thus, at 1000 Hz, significant diffraction effects are visible, due to the presence of a Reg reflector in the near zone.

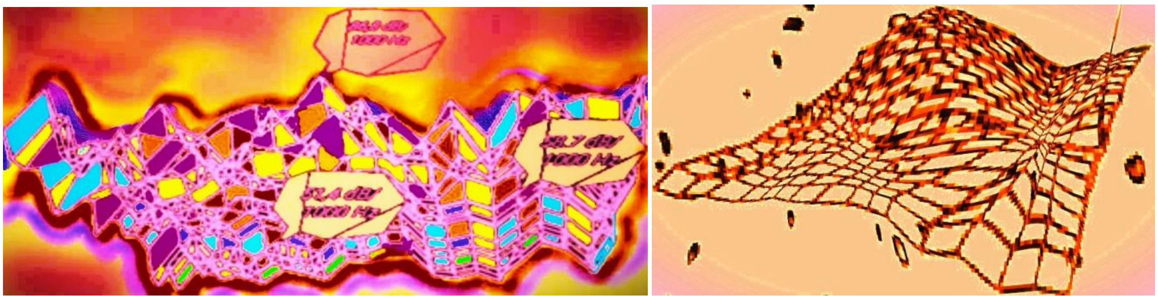

Fig. 4. The intensity distribution of sound pressure on the isobar Reg

5 DISCUSSION OF RESEARCH RESULTS

It should be noted that the algorithm does not directly use formula (7), but only its integrand. The construction site is set by the user in the form of a set of polygons, which approximate all surfaces that are essential for the model. Polygons, in turn, are discretized to a set of points and the surrounding areas σ. Each such element becomes an elementary point radiator radiating into a half-space.

A large degree of discretization will give the best results, on the other hand, the number of discrete emitters directly affects the performance of the algorithm. In COMSOL, many simulations were performed at different frequencies with different sizes of elementary emitters. Comparison of the results is shown in Fig. 5. The error was considered to be a relatively high degree of discretization with an element size of about 10 ". The graph in Fig. 5 illustrates that the optimal size of an elementary radiator must not exceed the wavelength of the calculated octave. When this value is exceeded, the accuracy drops sharply.

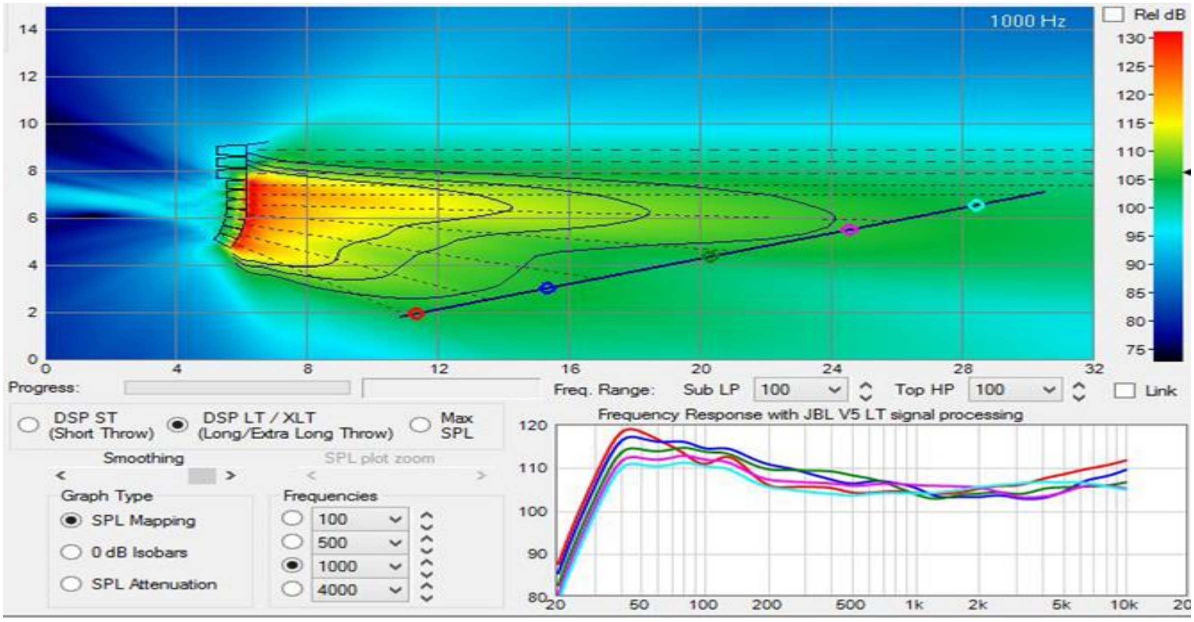

Fig. 5. Choosing the optimal reverberation size of the elementary polygon

6 CONCLUSIONS

Today, parallel and distributed computing is becoming increasingly popular and widespread, as the dimensions of a logical element approach the lower theoretically possible boundaries due to quantum effects and energy costs. Therefore, already at the stage of developing algorithms for solving any problem, subject matter experts and programmers need to ensure the parallelism of algorithms taking into account the requirements and constraints arising from the architecture of the software and hardware platform used.

This paper presents a model of the propagation of the acoustic field in open and combined spaces, which can reflect the diffraction properties during the propagation and reflection of sound. Based on the model, an algorithm can be compiled for further implementation in a formal language.

7 GRATITUDES

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8 ETHICAL DECLARATIONS

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