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E-mail: worldscience.uae@gmail.com

Tel. +971 56 498 67 38

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ALGORITHMS FOR SOLVING INVERSE PROBLEMS ACOUSTICS

Tyulepberdinova G. A.,
Adilzhanova S. A.,
Gaziz G. G.

Kazakhstan, Almaty, Al-Faraby Kazakh National University

Abstract. *This article describes an algorithm for solving inverse acoustic problem. Imagine the acoustic equation in finite-difference form. By approximating the boundary condition, and assuming that all functions are sufficiently smooth, we can write the inverse problem in finite-difference form. The following describes the algorithms for solving inverse acoustic method of treatment of a difference scheme, approximation method Landweber method, the method of discrete approximation Landweber method. In C ++ was chosen as the programming language. For brevity, we use the style of Kernighan and Ritchie.*

Keywords: *algorithm for solving the inverse problem, finite difference form, the method of treatment of a difference scheme, approximation method, the method Landweber, metodm discrete approksimatsiida.*

Introduction

The following describes the algorithms for solving inverse acoustic method of treatment of a difference scheme, approximation method Landweber method, the method of discrete approximation Landweber method. In C ++ was chosen as the programming language [1,2]. For brevity, we use the style of Kernighan and Ritchie [3]. We introduce the mesh x = ih, t = kh. We represent the equation of acoustics [4] in the finite-difference form

$$\frac{u_i^{k+1} - 2u_i^k + u_i^{k-1}}{h^2} = \frac{u_{i+1}^k - 2u_i^k + u_{i-1}^k}{h^2} - 2\frac{(s_{i+1} - s_{i-1})}{h(s_{i+1} + s_{i-1})} \cdot \frac{u_{i+1}^k - u_{i-1}^k}{2h}, \tag{1}$$

from expressing u_{i+1}^k we get

$$u_{i+1}^k = \frac{(u_i^{k+1} + u_i^{k-1})(s_{i+1} + s_{i-1}) - 2u_{i-1}^k s_{i+1}}{2s_{i-1}}. \tag{2}$$

Approximate boundary condition

$$u_i^k = u_0^k + h\left.\frac{\partial u}{\partial x}\right|_{x=0} + \frac{h^2}{2}\left.\frac{\partial^2 u}{\partial x^2}\right|_{x=0} + 0(h^2)$$

$$= u_0^k + \frac{h^2}{2}\left(\frac{u_0^{k+1} - 2u_0^k + u_0^{k-1}}{h^2} + 2\frac{s'(0)}{s(0)}\left.\frac{\partial u}{\partial x}\right|_{x=0}\right) + 0(h)^2$$

$$= \frac{u_0^{k+1} + u_0^{k-1}}{2} + 0(h)^2.$$

Thus, assuming that all the functions in question are sufficiently smooth, we can write the inverse problem in finite-difference form

$$u_{i+1}^k = \frac{(u_i^{k+1} + u_i^{k-1})(s_{i+1} + s_{i-1}) - 2u_{i-1}^k s_{i+1}}{2s_{i-1}}. \tag{3}$$

$$u_1^k = \frac{u_0^{k+1} + u_0^{k-1}}{2}, \tag{4}$$

$$u_i^i = s_i, \tag{5}$$

$$u_0^k = g_k. \tag{6}$$

Substituting k = i + 1 in the expression (3) and taking into account (5), we obtain the formula for calculation of unknown function

$$s_{i+1} = s_{i-1} \frac{u_i^{i+2} + s_i}{2s_{i-1} - s_i - u_i^{i+2} + 2u_{i-1}^{i+1}}. \tag{7}$$

The calculations will be carried out on border i = 0 along performance. first count s_0, then, knowing the value of u_0^2, compute s_1. More from u_0^4, calculating along the characteristics, define s_2 and so on. The following describes the algorithms by the following methods for solving the inverse acoustic problem:

- A method of treatment of the difference scheme;
- Approximation method Landweber;
- Discrete approximation method Landweber.

1. realization Method of treatment of the difference scheme

We describe in detail the implementation of the algorithm method of treatment of the difference scheme.

Below is a snippet of code listing, which describes the classified variables and constants problem.

```
const int N = 200; // The number of grid points.
const Real l = 1; // The size of the field.
const Real h = l / N; // a step of temporal and spatial grid.
const Real noise_param = 0.05; // noise parameter.
RealVector x(N+1, 0); // coordinate argument. RealVector t(2*N+1, 0); // The time argument.
RealVector S(N+1, 0); // Расчитываемая функция S(x). RealVector S_ex(N+1, 0); // the exact function S(x).
RealMatrix u(N+1, 2*N+1, 0); // The solution of the direct problem. RealMatrix v(N+1, 2*N+1, 0); // The solution of the inverse problem.
RealVector f_ex(N+1, 0); // accurate f(t) := u(0,t); RealVector f(N+1, 0); // noisy f(t) := u(0,t);
```

Initializing the input parameters is implemented as follows:

Calculate values of the axes.

```
for(i = 0; i <= N; x[i] = h * i++);
for(k = 0; k <= 2*N; t[k] = h * k++);
```

We specify the exact function S(x).

```
SetS(x, S);
 S_ex = S;
```

Where the function SetS() sets values S(x) a linear, quadratic or periodic function, depending on the application settings.

To solve the problem of creating a direct function
SolveDirectProblemByFiniteDifferenceMethod() interface with the following:

Input parameters:

S – function S(x) (the input data of the problem).

Output parameters:

u – function u(x,t) (solution of the problem in the whole region),

f – following the direct problem solution u(0, t).

Ie as the realization of the direct problem solution method of treatment of the difference scheme is simple, we give below the listing function code.

```
void SolveDirectProblemByFiniteDifferenceMethod(
const RealVector & S,// S(x).
RealMatrix & u,// u(x,t).
RealVector & f // g(t) := u(0,t).
){
int i, k;
// We set u(x,x).
for(i = 0; i <= N; ++i) { u(i,i) = S(i); }
// Compute u(x,t). for(k = 1; k <= N; ++k) for(i = 1; i <= k; ++i){ if(i == k)
u(0, k+i) = 2 * u(1, k+i-1) - u(0, k+i-2);
else
u(k-i,k+i) = (2.*u(k-i+1, k+i-1) * S(k-i-1)
+ 2.*u(k-i-1, k+i-1) * S(k-i+1)) / (S(k-i+1) + S(k-i-1))
- u(k-i, k+i-2);
}
// Compute g(t).
for(k = 0; k <= N; ++k){ f(k) = u(0, 2*k); }
}
```

To solve the inverse problem of creating function SolveInverseProblemByFiniteDifferenceMethod() interface with the following:

Input parameters:

f – function f(x) (the input data of the problem).

Output parameters:

v – function v(x,t) (the solution of the inverse problem in the whole region),

S – inverse problem S(x).

Here is a complete listing of the function code.

```
void SolveInverseProblemByFiniteDifferenceMethod(
const RealVector & f,// f(x).
RealMatrix & v,// v(x,t).
RealVector & S // S(x).
){
// We set v(0,k).
for(k = 0; k <= N; ++k) { v(0,2*k) = f(k); }
// S(0) S(0) = f(0);
// Compute v(1,k).
for(k = 1; k <= 2*N-1; k += 2){
v(1,k) = (v(0,k+1) + v(0,k-1)) / 2.;
}
S(1) = v(1,1);
// Compute v(i,k).
for(i =1; i <= N-l; ++i){
for(k = i+1; к  <= 2*N-i-l; ++k){
S(i+1) = S(i-l) * (v(i,i+2) + S(i))
/ (2.*S(i-l) - S(i) - v(i,i+2) + 2.*v(i-l,i+1));
v(i+l,k) = (v(i,k+l) + v(i,k-l)) * (S(i+1) + S(i-D)
/ (2 * S(i-l)) - v(i-l,k) * S(i+1) / S(i-l);
}}}
```

further describe the general implementation of the scheme, omitting for brevity code responsible for saving data to a file.

1 We specify the exact function S(x), function call SetS(x, S);

2 We remember the exact value of the function S(x) variable S_ex = S;

3 function call SolveDirectProblemByFiniteDifferenceMethod(S, u, f), We solve the direct problem for a given S(x), we find u(x,t) и f(t).

4 We remember the exact value of the function f(x) variable f_ex = f;

5 add noise, a function call AddNoise(f, noise_param);

6 "Forget" about the solution of the direct problem: S = 0;

7 function call SolveInverseProblemByFiniteDifferenceMethod(f, v, S), We solve the inverse problem for a given f(x), we find S(x) и v(x,t);

8 We derive and compare values S_ex и S.

In the future, instead of the full implementation of the listing functions will give a brief description of the interface and the implementation of the scheme.

2. The implementation of the approximation method Landweber iteration

We describe the implementation of the schematic approximation method Landweber iterations. One of the basic principles of programming is to write code pereispolzuemogo [4]. We will use the following code, written to solve the problem using the method of treatment of the difference scheme:

- SetS(x, S_ex);
- SolveDirectProblemByFiniteDifferenceMethod(S_ex, u, f);
- AddNoise(g1, noise_param);

Here is the description of the main variables of the problem.

RealMatrix ql(N+l, 2*N+1, 0);

RealVector q2(N+l, 0); // q_2 = 1 / s(x).

RealVector q3(N+l, 0); // q_3 = 2*s'(x)/s(x)

RealMatrix wl(N+l, 2*N+1, 0); // discrepancy. RealVector w2(N+l, 0);

RealVector w3(N+l, 0);

RealMatrix Adjl(N+l, 2*N+1,0); // the solution of the dual problem.

RealVector Adj2(N+l, 0);

RealVector Adj3(N+l, 0);

RealMatrix gl(N+l, 2*N+1, 0); // Additional Information.

Real g2;

RealVector g3(N+l, 0);

RealVector f(2*N+l, 0); // More information in the original statement.

RealVector S(N+1, 0); // decision in the original formulation.

RealVector S_ex(N+l, 0);

We now describe the overall implementation of the scheme, lowering implementation functions for evaluating integrals [5,6].

1 Specify the exact function S (x), a function call SetS(x, S);

2 memorize the current value of S (x) function in the variable S_ex = S;

3 function call SolveDirectProblemByFiniteDifferenceMethod(S, u, f), solve the direct problem for the set S (x), we find u(x,t) и f(t).

4 memorize the current value of the function f (x) in the variable fex = f;

5 Initialize the additional information in the integral formulation

$$g(x,t)=(g_1(x,t),g_2,g_3(x));$$

6 Initialize the exact solution for the integral statement $q(x,t)=(q_1(x,t),q_2(x),q_3(x));$

7 add noise, a function call AddNoise(g1, noise_param);

8 "Forget" about the solution of the direct problem: S = 0;

9 given initial approximation: q = 0;

10 we calculate the discrepancy w1, w2, w3;

11 check the condition of stopping the discrepancy w1, w2, w3, if fulfilled, then go to step 15;

12 We calculate the solution of the dual problem Adj1, Adj2, Adj3;

13 We calculate the next approximation: q1 -= alpha1 * Adj1, ...;

14 go to step 10;

15 calculate S[k] = 1. / phi2[k];

16 We derive and compare values S_ex и S.

3. Implementation of discrete approximation method Landweber iteration

Driving the implementation of discrete approximation method Landweber iteration coincides with the implementation of the scheme approximation method Landweber iteration. The big difference is in the calculation of direct and dual problem[7]. As a result of this algorithm can be carried out numerical experiment on solving inverse acoustic problem by the treatment of the difference scheme (linear function s(x), noise parameter □≈0.014; periodic function s(x), noise parameter □ ≈ 0.014; step function s(x), noise parameter ≈ 0.002; step function s(x), noise parameter ≈ 0.01); can be carried out numerical experiment on solving inverse acoustic problem by Landweber iterations (linear function s(x), noise parameter ≈ 0.01; s(x) - parabola, noise parameter ≈ 0.13; periodic function s(x), noise parameter ≈ 0.002); It can be carried out numerical experiment on solving a discrete inverse acoustic problem by Landweber iterations;

In conclusion, it can be determined by algorithms when the input data of the problem are given exactly that error is equal to zero, to solve the inverse acoustic problem will effectively use a method in the case where the data set is inexact and there is no hard limit on the execution time estimates or need to calculate with low accuracy and in the case where there are restrictions on time performance and high accuracy is required calculations.

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МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ ТЕРМООБЕСЦВЕЧИВАНИЕ ДЫРОЧНЫХ V_2-ЦЕНТРОВ ОКРАСКИ В КРИСТАЛЛАХ NaCl С РАЗЛИЧНЫМИ КОНЦЕНТРАЦИЯМИ Ag

[1]Осконбаев М. Ч.,
[2]Абдимуталипова З. К.,
[3]Мамытова Н.,
[4]Ураимова К.,
[5]Осмоналиев А. Б.,

Кыргызстан, г. Ош, Ошский государственный университет,
[1]к. ф.-м. н., доцент ОшГУ,[2]магистр ОшГУ,[3]магистр ОшГУ,[4]аспирант ОшГУ,[5]к. ф.-м. н., доцент ОшГУ

Abstract. *The mathematical model and the program is made to study the behavior and termoobestsvechivanie hole color centers in ionic crystals*

Keywords: *crystal, mathematical model, color center,hole, ion, polynomial*

Цель статьи - на основе полученных экспериментальных данных по термообесвечиванию дырочных V_2 –центров окраски в кристаллах NaCl с различными концентрациями Ag разработка математической модели термообесцвечивания дырочных центров. Разработка и апробация алгоритма решения поставленной задачи на основе полученной математической модели. На основе полученного алгоритма составить программу, реализующей полученную математическую модель на компьютера. Осуществлять сопоставительный анализ между экспериментальными данными и результатами, полученными на компьютере по алгоритму разработанной математической модели. Полученные на компьютера результаты показали соответствие этих результатов с экспериментальными данными.

The purpose of the article: to develop a mathematical model of thermal fading of hole centers based on the experimental data obtained by the electronic thermal fading of hole V_2-color centers in NaCl crystals with different Ag concentrations. To develop and test the algorithm to solve this problem on the basis of the mathematical model. To write a program that implements the resulting mathematical model on a computer on the basis of this algorithm. To carry out a comparative analysis between the experimental data and the results obtained by computer due to the algorithm of the developed mathematical model. The computer results showed the matching of these results with the experimental data.

Мы в своих исследованиях имеем четкую адекватную постановку физической задачи. Для решения этой задачи построена математическая модель, в которой использован интерполяционный полином Ньютона. На основании построенной модели составлена программа для решения задачи на ЭВМ.

Экспериментальное и теоретическое исследования процессов распада и преобразование различных по структуре радиационных центров показали, что в процессе распада и взаимопревращения радиационных дефектов в области высоких температур основную роль играют ионные процессы, протекающие в ЩГК [1-2].

В работе [3] была рассмотрена математическое моделирование термолюминесценции в кристаллах NaCl с различной концентрацией серебро. В работе [4] была рассмотрена математическое моделирование термообесцвечивание электронных F- центров окраски в кристаллах NaCl с различной концентрацией серебро. В работе [5] была рассмотрена математическое моделирование термообесцвечивание дырочных Ag_a^-- центров окраски в кристаллах NaCl с различной концентрацией серебро.

В данной работе было попытка определить с помощью первой интерполяционной формулы Ньютона начальное и конечное значения функции и поведение термообесцвечивания дырочных V_2-центров окраски в кристаллахNaClс различными концентрациями Ag.

Если принять полученные экспериментальные данные за узловые точки, то можно провести анализ поведения распада и взаимодействия,дырочных V_2- центров окраски в близлежащих к узловым точках, используя современные методы интерполяции.

Считая J функцией от температуры и принимая значения температуры за узлы интерполирования, интерполируем заданную табличную функцию J. Так как в нашем случае узлы равноотстоящие, будем пользоваться интерполированным полиномом Ньютона в следующем виде:

$$P_n(x) = y_0 + q\Delta y_0 + \frac{q(q-1)}{2!}\Delta^2 y_0 + \ldots + \frac{q(q-1)\ldots(q-n+1)}{n!}\Delta^n y_0 \qquad (1)$$

где $q = \frac{x - x_0}{h}$, $x_i = x_0 + ih(i = 0,1,2..h)$, $\Delta^n y_i = \Delta^{n-1} y_{i+1}$

На рисунке 1 показаны экспериментальные результаты термообесцвечивания дырочных V_2- центров окраски в кристаллах NaCl с различными концентрациями серебра. На полиномах (Полином 1-6) показаны математическое моделирование V_2-центров окраски с различными концентрациями серебро в кристаллах NaCl.

Сопоставление экспериментальных данных термообесцвечивания дырочных центров окраски с результатами, полученными на ЭВМ показывают, что построенная математическая модель достоверно описывает исследуемый физический процесс.