QIR

The 7th International Conference Quality in Research (QIR) 2004

PROCEEDING

"Quality Enhancement in Research Towards Global Competition"

Depok, 4 - 5 Agustus 2004

Electrical and Electronics Engineering :

" Frontiers in Electrical and Electronic Engineering: Toward a Deeper Knowledge "

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PROSIDING
Quality In Research Ke 7
Fakultas Teknik Universitas Indonesia
ISSN : 1411 - 1284

Prosiding QiR 2004 mempublikasikan makalah makalah yang dipresentasikan dalam Seminar Quality In Research yang dilaksanakan di Fakultas Teknik Universitas Indonesia. Seminar QiR ini dilaksanakan rutin setiap tahun pada awal semester ganjil dan merupakan wadah untuk penyebaran informasi dan publikasi hasil penelitian yang dilakukan oleh peneliti dan praktisi dari berbagai universitas dan instansi, pemerintah maupun swasta.

Seminar QiR 2004 ini merupakan kegiatan yang ketujuh dan bertemakan "Quality Enhancement in Research towards Global Competition."

Sekretariat Redaksi	: Gedung Dekanat FTUI Universitas Indonesia, Kampus Baru UI Depok, 16424
Rekening Bank	: Bank BNI 46 Cab.UI-Depok, Rek. No.273.004.049.886.901
Terbit Pertama	: August 1998
Frekuensi Terbit	: Satu tahun sekali
Penerbit	: Fakultas Teknik Unversitas Indonesia Kampus UI Depok 16424

FOREWORDS FROM
Dean of Faculty of Engineering, University of Indonesia

The Conference on Quality in Research (QiR) is an annual event organized by the Faculty of Engineering - University of Indonesia, in the month of August every year. Since started in 1998, it has become an excellent forum of discussion for all researchers from research Institutions and Universities all over the country of Indonesia. In the past years, the 1st to the 6th Conference on QiR, had been successfully organized as a high quality national conferences, and starting from this year, the conference has been organized to invite presentations of research papers internationally.

The 7th Conference on Quality in Research having a theme of "Quality Enhancement in Research towards Global Competitions" is to provide an international forum for the exchange of the knowledge, research information, experience and results as well as the review of progress and discussion on the state-of-the-art and future trends in engineering for bettering human life. Through the active participation of all delegates in the fruitfull discussions in this conference, it is hope that more closely collaborations amongst researchers and research institutions will be developed in the short coming future to achieved a better and higher quality in research nationally as well as internationally.

We would like to express our heartiest thanks to all the authors and participants for their active participations in the 7th International Conference on Quality in Research - QiR 2004, and also to all the paper-reviewers, member of the technical committees, and member of the organizing committees, for their support to the success of this conference. Last but not least, We would also like to invite all participants to the next Conference on Quality in Research -QiR 2005 in August 2005.

Faculty of Engineering
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Rinaldy Dalimi Ph.D.

FOREWORDS

The 7th Conference on Quality in Research having a theme of "Quality Enhancement in Research towards Global Competitions" being the first time to go internationally, has invited limited papers from other country like Japan, Malaysia and Singapore. The conference is organized covering a large area of research in Engineering and Management, including Civil Engineering, Mechanical Engineering, Electrical Engineering, Metalurgy and Materials, Industrial Engineering, Project Management, Optoelectronics and Laser Applications. The conference is organized in parallel session focusing on the 6(six) research areas such that many researchers and peer groups may focus their discussions on the relevant topics. All submitted papers had been reviewed by the technical committees appointed and had been arranged in to 6(six) sub-theme according to the following fields :

1. in Civil Engineering :
   "Environment Friendly Infra-structure Development for Sustainable Future"
2. in Mechanical Engineering :
   "Recent Progress in Energy, Design and Manufacturing Engineering"
3. in Electrical Engineering :
   "Frontiers in Electrical and Electronic Engineering: Toward a Deeper Knowledge"
4. in Metalurgy and Material Engineering :
   "Quality Enhancement in Research on Materials Design and Processing Toward a Sustainable Materials Policy"
5. in Industrial Engineering :
   "Quality and Process Improvement"
6. in Opto Electrotechniques and Laser Applications :
   "Opto-Electrotechniques and Laser Applications: Support the Future Technologies"

The main purpose of the conference is to provide an international forum for the exchange of the knowledge, research information, research experience and results as well as the review of progress and discussion on the state-of-the-art and future trends in computation method, research experiments, development of theory, concept of thinking and applications as well as their tools applied to all engineering fields for bettering human life.

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CONTENT

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ISSN 1411-1284

Adaptive Multiresolution Scheme Based on Haar Wavelets For Acoustic Wave Propagation

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Abstract — **In this paper, we present the multiresolution time-domain method (MRTD) based on Haar wavelets for acoustic wave propagation. The numerical method has the ability to represent functions at different levels of resolution. Wavelets are localized in space, which means that the solution can be refined in regions of high pressure gradient without having to regenerate the mesh for the entire domain We employ a mesh adaption in physical space dynamically using wavelet thresholding to follow the propagation of the wave. Using grid adaption, the computational effort can be reduced. Computed acoustic fields are compared to the exact solution, the comparison shows a good agreement.**

Keywords — **adaptive, multiresolution time-domain, Haar wavelet, acoustic fields.**

1. Introduction

Recently wavelet theory has been a field intensive reseach for mathematicians and engineers. The properties of wavelet such as time/space and frequency localization encouraged many researchers to study wavelet for solving partial differential equations [1]. Wavelet based techniques have shown significant promise in area of numerical modeling of of physical phenomena that contain high gradient or sharp transition [2]. Examples of the later are formation of shock waves, electromagnetic and acoustic wave propagation. The modelling of engineering system involving acoustic wave interactions was dominated by frequency-domain methods. The frequency-domain methods can not be applied for nonlinear problems and broadband linear excitations.

For those reasons, time-domain methods have greater potential for solving complex problems than frequency-domain methods. Time-domain methods directly simulate the physical systems by making discrete approximation for the time and spatial derivatives to turn the partial differential equations into a system of algebraic equations. Yee introduced the first time-domain method in 1966 [3]. This method computes electric and magnetic fields that are staggered in space and time and can be interpreted as standard leapfrog method and well known as Yee's scheme FDTD. Based on Yee's scheme, Botteldoreen developed finite difference time domain for solving room acoustic problems [4]. Schneider et al. used FDTD for solving scattered acoustic waves [5].

Some new schemes have also started with Yee's scheme but were extended for greater accuracy rather than for geometry. Nguyen used upwind leapfrog method for solving acoustics and electromagnetics [3]. Kim developed upwind leapfrog for solving acoustic and aeroacoustic wave propagation problems [6]. More recently work on multiresolution time-domain techniques have been published by Katehi's group from University of Michigan [2,7,8]. They developed multiresolution time-domain (MRTD) method to analyze electromagnetic fields. In the MRTD scheme, the field components are expanded by using scaling and wavelet function then tested with using scaling and wavelet function through Galerkin's procedure. In this paper, Haar scaling and wavelet function are used to represent pressure and velocity fields. Based on Dogaru's work, we extended MRTD method for solving acoustic equations [9,10].

2. Formulations

A. One-dimensional Formulation

The application of the MRTD method to the simple case of one-dimensional system of non-dimensionalyzed acoustic equations is considered.

$$\frac{\partial u}{\partial t} = -\frac{\partial p}{\partial x} \qquad (1a)$$

$$\frac{\partial p}{\partial t} = -\frac{\partial u}{\partial x} \qquad (1b)$$

The spatial variation of pressure and velocity fields is defined by a basis composed of scaling and wavelet functions. The Haar scaling functions are defined as orthogonal translations:

$$\phi_k(x)=\phi\left(\frac{x}{\Delta x}-k\right) \tag{2}$$

of $\phi(x)=\chi_{[0,1)}(x)$, with $\chi_{[a,b)}(x)=1$, when $x\in[a,b)$ and zero otherwise. In this notation Δx is the cell size in x-direction. Haar wavelet function is defined as:

$$\psi_k(x)=\psi\left(\frac{x}{\Delta x}-k\right) \tag{3}$$

The function $\psi(x)=\chi_{[0,1/2)}(x)-\chi_{[1/2,1)}(x)$, whose dilations and translations yield the wavelet basis, is the well-known Haar mother wavelet function.

The temporal variation of fields is described in terms of pulse functions

$$h_k(t)=h\left(\frac{t}{\Delta t}-k\right) \tag{4}$$

with $h(t)=\chi_{[0,1)}(t)$ and Δt being the time step.

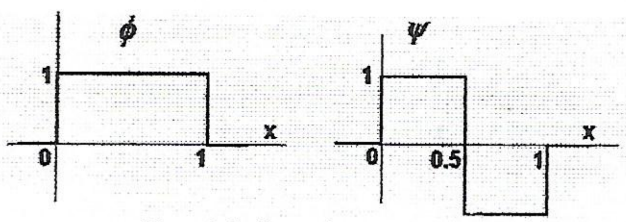

Figure 1. Scaling and wavelet function

We consider the expansion of velocity and pressure fields using scaling functions and one level wavelet functions:

$$u=\sum_{i=0}^{I}\sum_{n=0}^{N}h_n(t)\left(u^{\phi}_{i,n}\phi_i(x)+u^{\psi}_{i,n}\psi_i(x)\right) \tag{5a}$$

$$p=\sum_{i=0}^{I}\sum_{n=0}^{N}h_{n+1/2}(t)\begin{pmatrix}p^{\phi}_{i+1/4,n+1/2}\phi_{i+1/4}(x)+\\ p^{\psi}_{i+1/4,n+1/2}\psi_{i+1/4}(x)\end{pmatrix} \tag{5b}$$

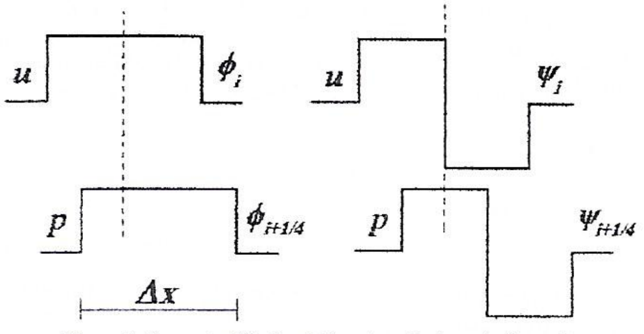

Figure 2. Support of the basis functions in the velocity and pressure expansions using one level of Haar wavelets

Figure 2 indicates that the support of the scaling/wavelet functions corresponding to velocity and pressure fields are displaced by one quarter of a cell. Now sample equation (1.a) according Galerkin's procedure, using $h_{n+1/2}(\phi_i(x)+\psi_i(x))$ as testing function.

$$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\left(\frac{\partial u}{\partial t}+\frac{\partial p}{\partial x}\right)h_{n+1/2}(t)\phi_i(x)dxdt=0$$
$$=\left(u^{\phi}_{i,n+1}-u^{\phi}_{i,n}\right)\Delta x+\begin{pmatrix}\left(p^{\phi}_{i+1/4,n+1/2}-p^{\phi}_{i-3/4,n+1/2}\right)+\\ \left(-p^{\psi}_{i+1/4,n+1/2}+p^{\psi}_{i-3/4,n+1/2}\right)\end{pmatrix}\Delta t \tag{6a}$$

$$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\left(\frac{\partial u}{\partial t}+\frac{\partial p}{\partial x}\right)h_{n+1/2}(t)\psi_i(x)dxdt=0$$
$$=\left(u^{\psi}_{i,n+1}-u^{\psi}_{i,n}\right)\Delta x+\begin{pmatrix}\left(p^{\phi}_{i+1/4,n+1/2}-p^{\phi}_{i-3/4,n+1/2}\right)+\\ \left(3p^{\psi}_{i+1/4,n+1/2}+p^{\psi}_{i-3/4,n+1/2}\right)\end{pmatrix}\Delta t \tag{6b}$$

The sampling process continues by testing equation (1.b) with $h_n(\phi_{i+1/4}(x)+\psi_{i+1/4}(x))$. After re-arranging the terms, the final expressions for the MRTD equations are:

$$u^{\phi}_{i,n+1}=u^{\phi}_{i,n}+\frac{\Delta t}{\Delta x}\begin{pmatrix}p^{\phi}_{i+1/4,n+1/2}-p^{\phi}_{i-3/4,n+1/2}\\ -p^{\psi}_{i+1/4,n+1/2}+p^{\psi}_{i-3/4,n+1/2}\end{pmatrix} \tag{7a}$$

$$u^{\psi}_{i,n+1}=u^{\psi}_{i,n}+\frac{\Delta t}{\Delta x}\begin{pmatrix}p^{\phi}_{i+1/4,n+1/2}-p^{\phi}_{i-3/4,n+1/2}\\ +3p^{\psi}_{i+1/4,n+1/2}+p^{\psi}_{i-3/4,n+1/2}\end{pmatrix} \tag{7b}$$

$$p^{\phi}_{i+1/4,n+1/2}=p^{\phi}_{i+1/4,n-1/2}+\frac{\Delta t}{\Delta x}\begin{pmatrix}u^{\phi}_{i+1,n}-u^{\phi}_{i,n}\\ +u^{\psi}_{i+1,n}-u^{\psi}_{i,n}\end{pmatrix} \tag{7c}$$

$$p^{\psi}_{i+1/4,n+1/2}=p^{\psi}_{i+1/4,n-1/2}+\frac{\Delta t}{\Delta x}\begin{pmatrix}-u^{\phi}_{i+1,n}+u^{\phi}_{i,n}\\ -u^{\psi}_{i+1,n}-3u^{\psi}_{i,n}\end{pmatrix} \tag{7d}$$

B. Extension to Two-Dimensions

The combination of a Haar scaling function and one wavelet level, in two-dimensions, is shown in figure 3.

The acoustic wave propagation is governed by the following equations:

$$\frac{\partial u}{\partial t}=-\frac{\partial p}{\partial x} \tag{8a}$$

$$\frac{\partial v}{\partial t}=-\frac{\partial p}{\partial y} \tag{8b}$$

$$\frac{\partial p}{\partial t}=-\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right) \tag{8c}$$

As an example, we discretize the equation (8c). The pressure field can be expanded using scaling and one level wavelet as

$$p = \sum_{i'=0}^{I}\sum_{j'=0}^{J}\sum_{n'=0}^{N} h_{n+1/2}(t)\begin{bmatrix} p^{\phi\phi}_{i+1/4,j+1/4}\phi_{i+1/4}(x)\phi_{j+1/4}(x)+ \\ p^{\phi\psi}_{i+1/4,j+1/4}\phi_{i+1/4}(x)\psi_{j+1/4}(y)+ \\ p^{\psi\phi}_{i+1/4,j+1/4}\psi_{i+1/4}(x)\phi_{j+1/4}(y)+ \\ p^{\psi\psi}_{i+1/4,j+1/4}\psi_{i+1/4}(x)\psi_{j+1/4}(y) \end{bmatrix} \quad (9)$$

With similar expressions for velocity fields. The testing functions for equation (8c) are:

$$h_n(t)\begin{pmatrix} \phi_{i+1/4}(x)\phi_{j+1/4}(y)+\phi_{i+1/4}(x)\psi_{j+1/4}(y)+ \\ \psi_{i+1/4}(x)\phi_{j+1/4}(y)+\psi_{i+1/4}(x)\psi_{j+1/4}(y) \end{pmatrix} \quad (10)$$

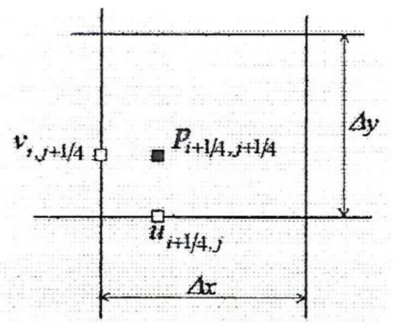

Figure 4. Velocity and pressure components displacement

The usual discretization procedure yields the following set of equations (only p update equations are given here):

$$\begin{aligned} p^{\phi\phi}_{i+1/4,j+1/4,n+1/2} &= p^{\phi\phi}_{i+1/4,j+1/4,n-1/2} - \\ &\frac{\Delta t}{\Delta x}\left(u^{\phi\phi}_{i+1,j+1/4,n} - u^{\phi\phi}_{i,j+1/4,n} + u^{\psi\phi}_{i+1,j+1/4,n} - u^{\psi\phi}_{i,j+1/4,n}\right) \\ &-\frac{\Delta t}{\Delta y}\left(v^{\phi\phi}_{i+1/4,j+1,n} - v^{\phi\phi}_{i+1/4,j,n} + v^{\phi\psi}_{i+1/4,j+1,n} - v^{\phi\psi}_{i+1/4,j,n}\right) \end{aligned} \quad (10a)$$

$$\begin{aligned} p^{\phi\psi}_{i+1/4,j+1/4,n+1/2} &= p^{\psi\phi}_{i+1/4,j+1/4,n-1/2} - \\ &\frac{\Delta t}{\Delta x}\left(u^{\phi\psi}_{i+1,j+1/4,n} - u^{\phi\psi}_{i,j+1/4,n} + u^{\psi\psi}_{i+1,j+1/4,n} - u^{\psi\psi}_{i,j+1/4,n}\right)+ \\ &\frac{\Delta t}{\Delta y}\left(-v^{\phi\phi}_{i+1/4,j+1,n} + v^{\phi\phi}_{i+1/4,j,n} - v^{\phi\psi}_{i+1/4,j+1,n} - 3v^{\phi\psi}_{i+1/4,j,n}\right) \end{aligned} \quad (10b)$$

$$\begin{aligned} p^{\psi\phi}_{i+1/4,j+1/4,n+1/2} &= p^{\psi\phi}_{i+1/4,j+1/4,n-1/2} - \\ &\frac{\Delta t}{\Delta x}\left(-u^{\phi\phi}_{i+1,j+1/4,n} + u^{\phi\phi}_{i,j+1/4,n} - u^{\psi\phi}_{i+1,j+1/4,n} - 3u^{\psi\phi}_{i,j+1/4,n}\right) \\ &+\frac{\Delta t}{\Delta y}\left(v^{\psi\phi}_{i+1/4,j+1,n} - v^{\psi\phi}_{i+1/4,j,n} + v^{\psi\psi}_{i+1/4,j+1,n} - v^{\psi\psi}_{i+1/4,j,n}\right) \end{aligned} \quad (10c)$$

$$\begin{aligned} p^{\psi\psi}_{i+1/4,j+1/4,n+1/2} &= p^{\psi\psi}_{i+1/4,j+1/4,n-1/2} - \\ &\frac{\Delta t}{\Delta x}\left(-u^{\phi\psi}_{i+1,j+1/4,n} + u^{\phi\psi}_{i,j+1/4,n} - u^{\psi\phi}_{i+1,j+1/4,n} - 3u^{\psi\phi}_{i,j+1/4,n}\right) \\ &+\frac{\Delta t}{\Delta y}\left(-v^{\psi\phi}_{i+1/4,j+1,n} + v^{\psi\phi}_{i+1/4,j,n} - v^{\psi\psi}_{i+1/4,j+1,n} - 3v^{\psi\psi}_{i+1/4,j,n}\right) \end{aligned} \quad (10d)$$

C. Wall Boundary Conditions

The boundary was assumed to be perfect electric conductor (PEC). MRTD scheme would model the PEC boundary conditions by means of image theory. This image theory is implemented by using ghost cell technique [6]. If a wall is flat and lies along x-axis (y = 0), the values for the ghost cells (for more details, see [10]) are:

$$p(x,-y) = p(x,y) \quad (11)$$

D. Stability Criteria

The classic Courant criterion for stability of the Yee FDTD scheme is [3]:

$$\Delta t\sqrt{\left(\frac{1}{\Delta x}\right)^2+\left(\frac{1}{\Delta y}\right)^2} \le 1 \quad (12)$$

The left hand side of equation (12) is known as Courant or CFL number.

Dogaru proved that the MRTD equations are equivalent to the Yee FDTD equations obtained for a grid with step $\Delta x/2$ and $\Delta y/2$ [9]. Therefore, the stability criterion for MRTD with one level wavelet is :

$$\Delta t\sqrt{\left(\frac{2}{\Delta x}\right)^2+\left(\frac{2}{\Delta y}\right)^2} \le 1 \quad (13)$$

For more details, see [7] .

3. Numerical Results

A. One-dimensional case

To evaluate the accuracy of MRTD scheme, the following initial conditions are taken to perform numerical simulations:

$$\begin{aligned} u(x,0) &= 0 \\ p\left(x,\frac{\Delta t}{2}\right) &= \exp\left(-\ln 2x^2/9\right) \end{aligned} \quad ; -100 \le x \le 100 \quad (14)$$

The results are compared to known exact solution, the exact solution in this case is:

$$u(x,t) = \begin{pmatrix} \exp\left(-\ln 2\left((x-t)^2\right)/9\right)+ \\ \exp\left(-\ln 2\left((x+t)^2\right)/9\right) \end{pmatrix}/2 \quad (15)$$

ISSN 1411-1284

We take Δt = 0.25 and Δx = 1. Figure 5 shows the convergence rate of the root mean square error over the time interval[0,50].

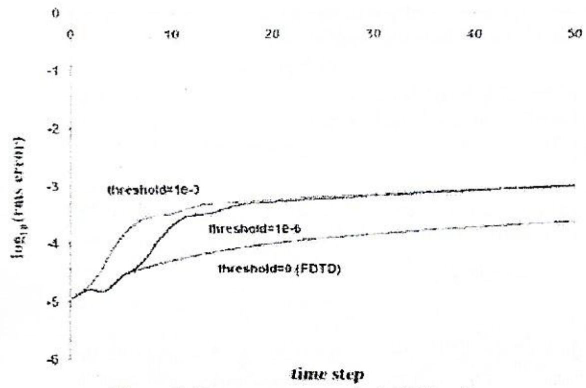

Figure 5. Convergence rate for MRTD scheme

FDTD errors and MRTD errors are almost linear in time. As the absolute threshold increases, the numerical accuracy decreases. For long time running, accuracies of absolute threshold=1e-3 and 1e-6 get closer. Comparisons with the exact solution are shown in figure 6 for pressure (p) profile, a good agreements are found.

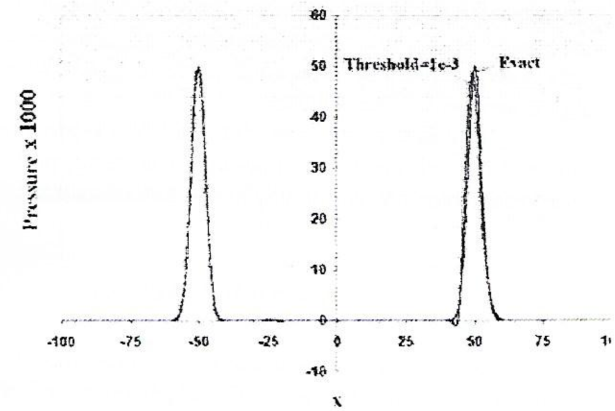

Fig. 6. Numerical solution of the 1-D acoustic problem at t=50,125

The number of coefficients for u and p after thresholding with absolute threshold=1e-6 and 1e-6 are compared to unthresholded coefficients (FDTD) for the same resolution.

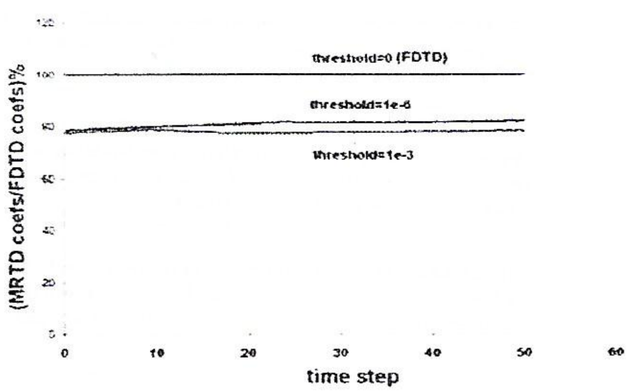

Fig. 7. Comparison of number coefficients in 1-d problem

B. Two-dimensional case

We next consider an acoustics wave propagation in a square cavity. We take the walls to be hard boundaries. The following initial conditions are applied:

$$u(x,y,0) = 0$$
$$v(x,y,0) = 0 \qquad ; \quad -100 \le$$
$$p\left(x,y,\frac{\Delta t}{2}\right) = exp\left(-ln\,2\,\frac{x^2+(y-25)^2}{9}\right)$$

$x \le 100$; $0 \le y \le 200$ (16)

We take Δt = 0.25, Δx = 1and Δy = 1. Figure 8a – 8d show the propagation of the acoustic wave.

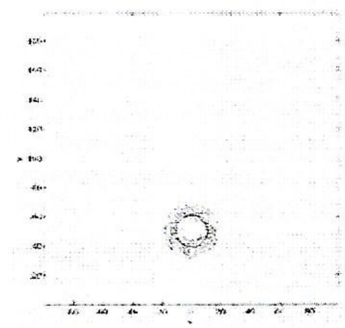

Figure 8a. Pressure at t = 12.625

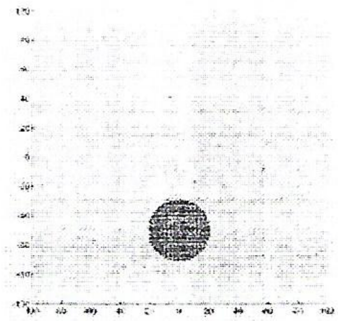

Figure 9a. Mesh at t = 12.625, threshold=1e-3

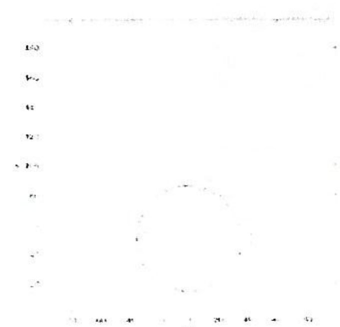

Figure 8b. Pressure at t = 37.625

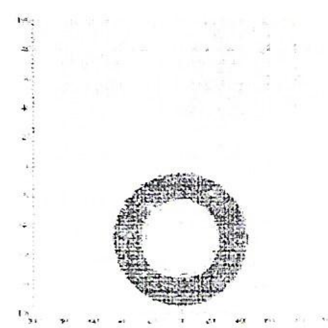

Figure 9b. Mesh at t = 37.625, threshold=1e-3

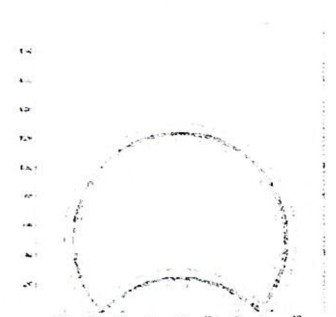

Figure 8c. Pressure at t = 75,125

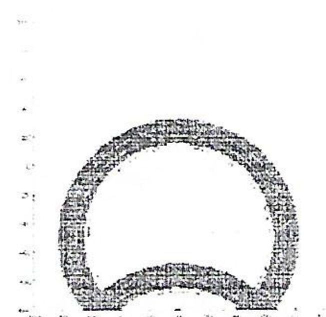

Figure 9c. Mesh at t = 75,125, threshold=1e-3

x=0. Computational effort can be reduced significantly using thresholding (figure 12).

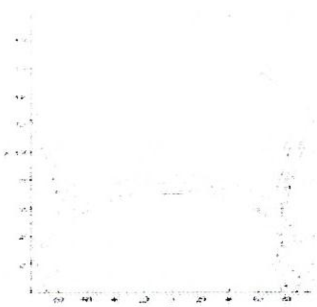

Figure 8d. Pressure at t = 125,125

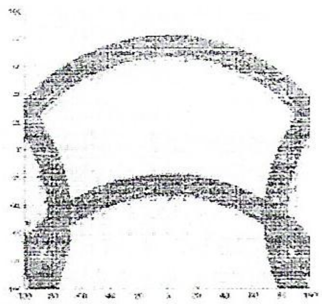

Figure 9d. Mesh at t = 125,125, threshold=1e-3

It can be seen that a new source of wave propagation is created at the point of reflection, each time an incident wave is reflected by the wall. The points of reflection and the point where the waves met have higher gradient pressure. The mesh will be refined in regions of high pressure gradient via wavelet thresholding (figure 9a –9d).

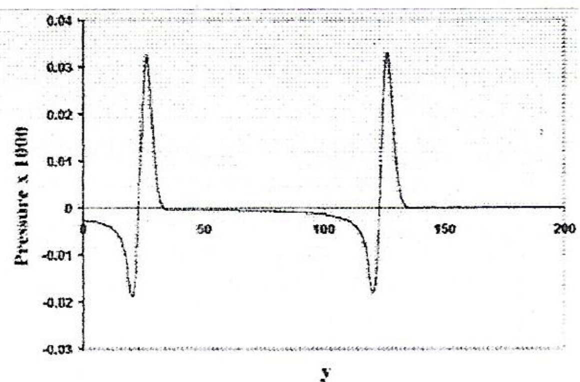

Figure 10. Pressure Profile at t = 75,125

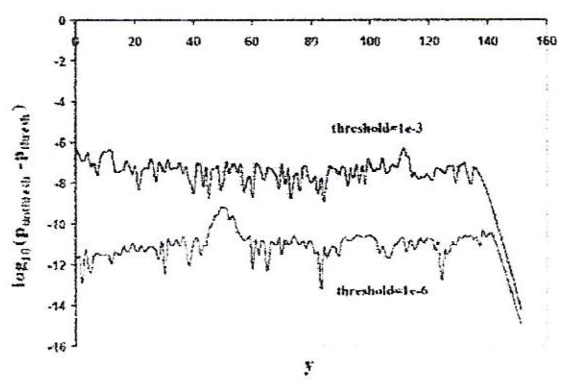

Figure 11. $log_{10}|p_{unthreshold} - p_{threshold}|$ at t = 75,125

Figure 10 & 11 show the pressure profile and absolute difference value of unthresholded and thresholded pressure at

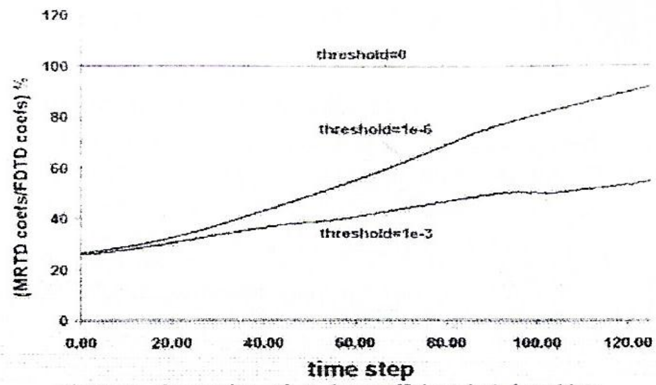

Figure 12. Comparison of number coefficients in 2-d problem

4. Conclusions

MRTD schemes based on Haar wavelet expansions are derived and applied in the numerical modeling of acoustic wave propagation. In this paper, it is shown that computational effort can be reduced without sacrificing solution accuracy. Implementation of the numerical is relatively simple and computed acoustic fields have a good agreement with exact solution.

For future research, we plan to extend the MRTD method for solving three-dimensional acoustic problems and use Daubechies wavelet family as the basis functions.

5. Acknowledgement

The authors acknowledge illuminating discussions with Dr. Traian Dogaru of Department of Electrical Engineering, The Duke University via e-mail on the MRTD method based on Haar wavelet.

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ISSN : 1411 - 1284