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REALIZING DIRECTIONAL SOUND SOURCE IN FDTD METHOD BY ESTIMATING INITIAL VALUE

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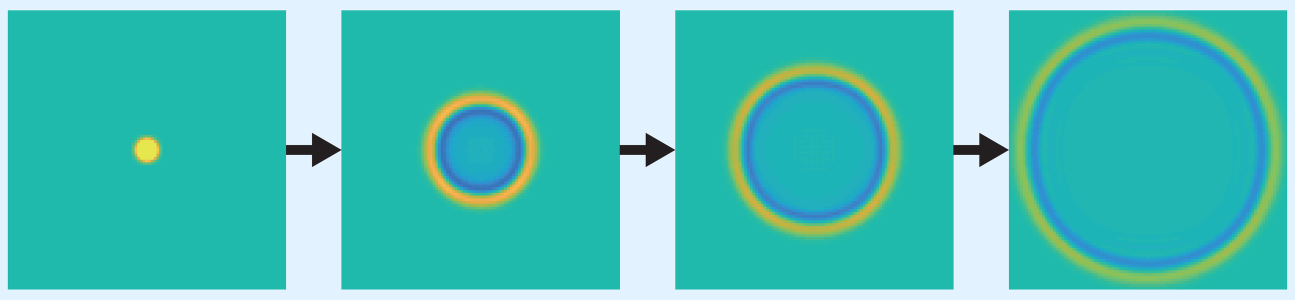
Introduction

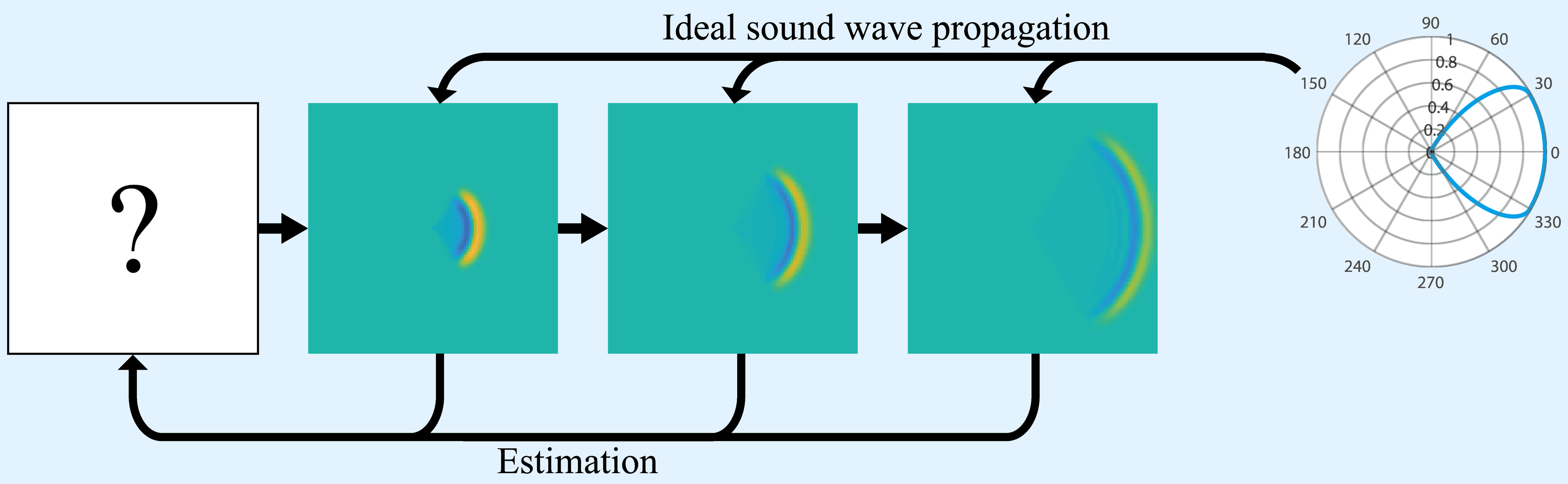
Finite-difference time-domain (FDTD) method is one of the most popular wave based acoustical simulation methods owing to its straightforwardness of calculating an impulse response. In an FDTD simulation, initial value of sound field decides the behavior of the wave propagation because FDTD methods have recursive scheme. However, most of FDTD simulations have been performed with an omnidirectional sound source which is not realistic because the real sound sources often have directivities.



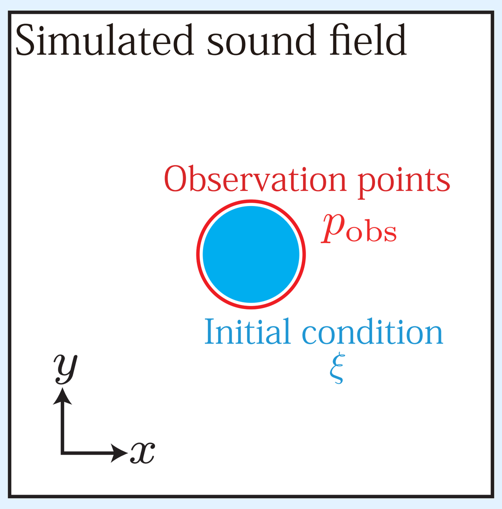
In this paper, a method of imposing a directional sound source into FDTD methods is proposed. By estimating initial value from desired directivity pattern, the directivity is approximately realized.

Formulation estimating initial value problem

In an FDTD simulation, initial value of sound field decides the behavior of the wave propagation. Therefore, the initial value which generate directional sound wave propagation can be estimated from a wave with the desired directivity pattern which is ideal created from the given pattern by multiplication



In the proposed method, the initial value is assumed to be compactly supported on a small region and directivity is evaluated at observation points. Therefore, estimating initial value problem is formulated as



$$\min_{\boldsymbol{\xi}} \|\mathrm{FDTD}(\boldsymbol{\xi}) - \boldsymbol{d}\|_2^2$$

where $\boldsymbol{\xi}$ is initial value vector, FDTD is operator of FDTD method and $\boldsymbol{d}$ is ideal wave propagation at observation points, respectively.

Matrix form of FDTD method

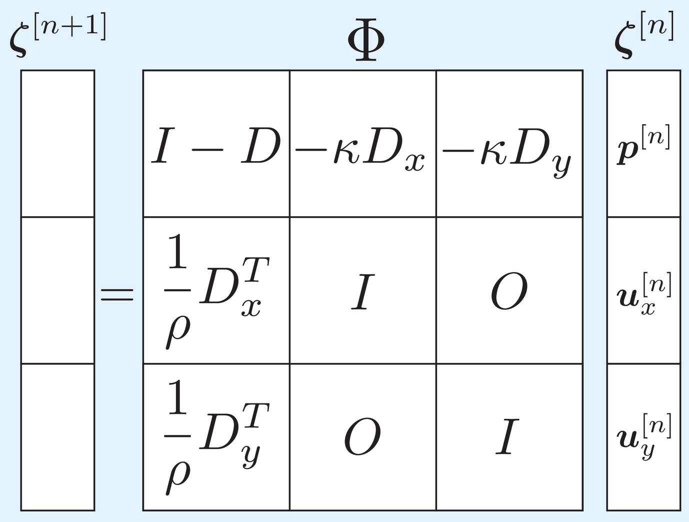
For solving this problem easily, matrix form of FDTD method is introduced. FDTD method can be rewritten as following matrix form:

$$u_x(n+1,i,j) = u_x(n,i,j) - \frac{\Delta t}{\rho \Delta h}\{p(n,i,j) - p(n,i-1,j)\}$$

$$u_y(n+1,i,j) = u_y(n,i,j) - \frac{\Delta t}{\rho \Delta h}\{p(n,i,j) - p(n,i,j-1)\}$$

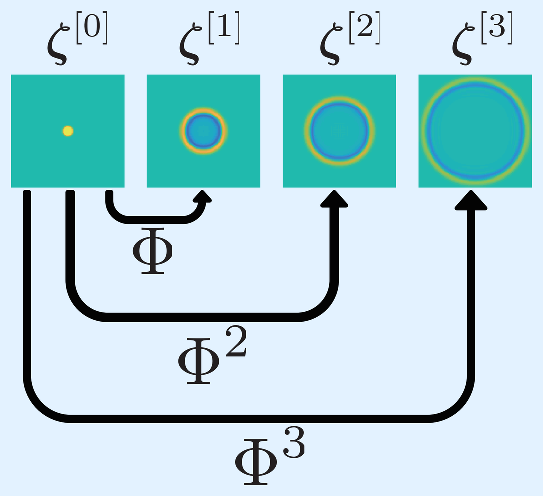
$$p(n+1,i,j) = p(n,i,j) - \frac{\kappa \Delta t}{\Delta h}[\{u_x(n+1,i+1,j) - u_x(n+1,i,j)\} + \{u_y(n+1,i,j+1) - u_y(n+1,i,j)\}]$$

$$\zeta^{[n+1]} = \Phi \zeta^{[n]} = \Phi^{n+1}\zeta^{[0]}$$



$$D = \frac{\kappa}{\rho}\left(\frac{\Delta t}{\Delta h}\right)^2 (D_x D_x^T + D_y D_y^T)$$

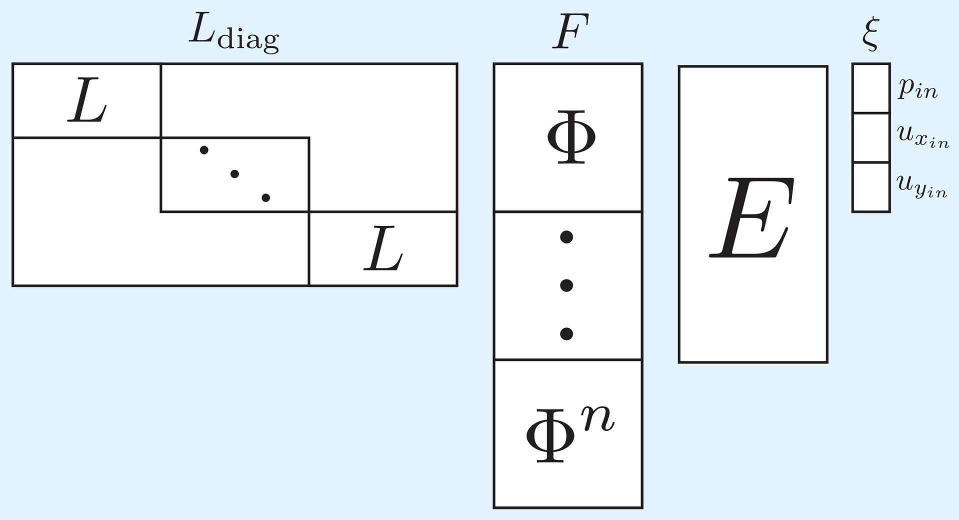
where Φ is matrix form of FDTD method, $\zeta^{[n]}$ is state vector, D is difference operator, I is identity matrix and O is zero matrix.



Formulation with matrix form of FDTD method

The least squares formulation with matrix form of FDTD method is written as following:

$$\min_{\boldsymbol{\xi}} \|L_{\mathrm{diag}} F E \boldsymbol{\xi} - \boldsymbol{d}\|_2^2$$



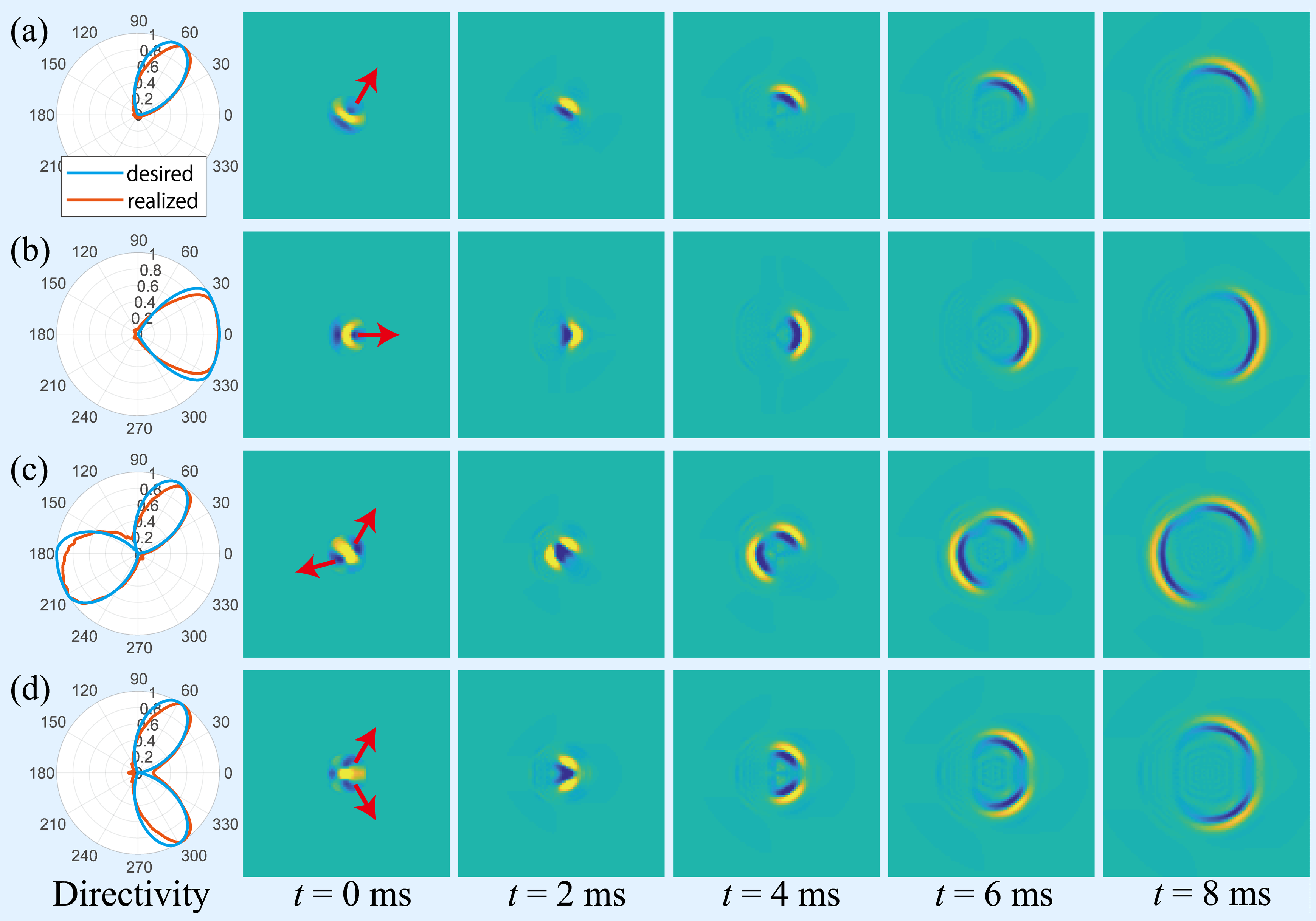
where E is expanding operator and L is observation operator. There are following relation:

$$\zeta^{[0]} = E\boldsymbol{\xi}$$

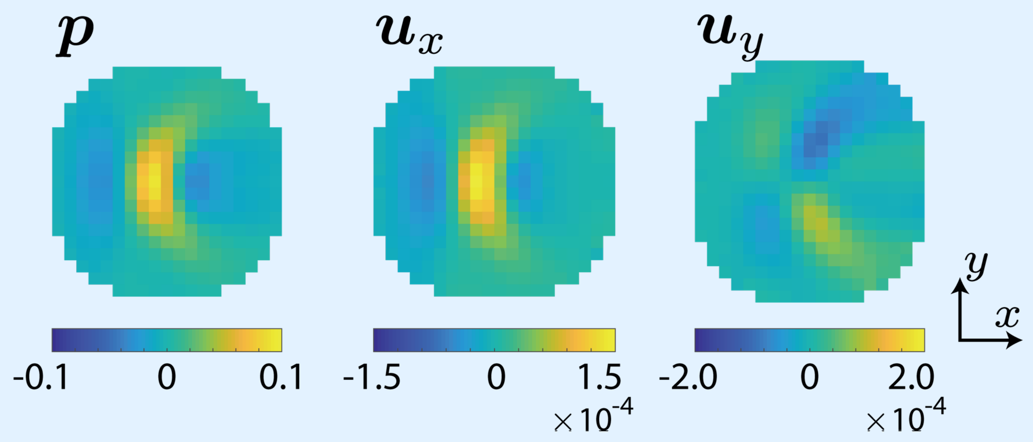
Numerical experiment

To confirm appropriateness of the proposed method, a numerical experiment was conducted. For solving least squares problem, LSMR solver was utilized. In such a iterative solver, explicit construction of matrix is not necessary because the result of matrix vector product only required.

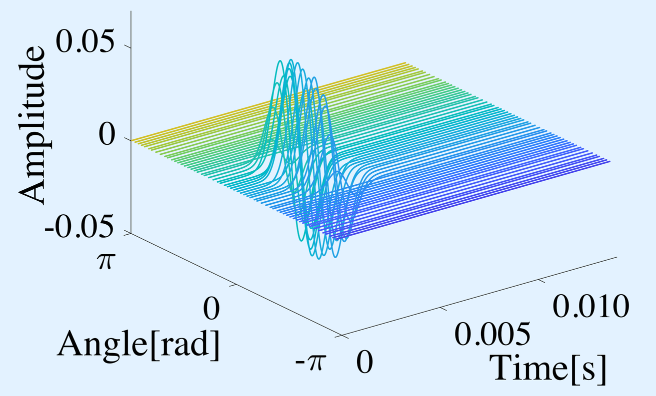
Simulation condition	
The size of sound field	10 m × 10 m
Shape of initial value Radius Size of initial value vector	Disk 1 m 997
Shape of observation points Radius No. of observation points	Circle 1.1 m 60
Sound speed	340 m/s
Density	1.21 kg/m^3
Spatial discretization interval	0.1 m
Time discretization interval	1/48000 s



Propagated waves generated by estimated initial value and their directivity



Estimated initial value corresponding to directivity (b)



Example of sound pressure at the observation point which constructs (a)

From propagated waves generated by estimated initial value, it can be confirmed that directional sound sources ware realized by proposed method. It can be seen that manually setting such an initial value is not an easy task even when the desired directivity is a simple pattern.

Conclusions

The method of realizing directional sound source by estimating initial value of an FDTD method was proposed. The proposed method can approximately impose any directivity pattern in FDTD method. Future works are investigation of the effect of the setting of the region of the initial value and observation points and analysis of the property of the matrix $L_{\mathrm{diag}}FE$.