3P-10

Proceedings of Symposium on Ultrasonic Electronics, Vol. 31 (2010) pp. 475-476
6-8 December, 2010

Simulation of Time Reversed Acoustic Focusing in Rectangular Room

Bok Kyoung Choi†, Jooyoung Hahn, Byoung-Nam Kim and Bong-Chae Kim
(Korea Ocean Research and Development Institute)

1. Introduction

A time reversal acoustics(TRA) technology has been mainly studied its principle and application by research teams as Fink[1-2], Sutin[3-4] and Kuperman[5]. Fink's research team invented the basic principle of taking the practical use of TRA technology in various fields. Sutin's research team has been studied the nonlinear acoustic focusing phemomena and Kuperman group has been performed the applied research in the marine sector.

The purpose of this study is to simulate the time reversed acoustic focusing using the impluse response model[6] in two-dimensional rectangular room. From this simulation we can see the spatial focusing characteristics of the time reversed acoustic focusing.

2. Basic Theory of TRA

Suppose to radiate a Gaussian pulse from a transmitter. Then the received signal at a receiving point in a room is given by the convolution of the emited signal, *e(t)* and the impulse response, *h(t)*.

$$s(t) = e(t) \otimes h(t) \quad (1)$$

Finally, the focused signal, *c(t)* at a receiving point is given by

$$c(t) = r(t) \otimes h(t) = s(-t) \otimes h(t) \quad (2)$$

where *r(t)* is the time reversed signal of *s(t)*.

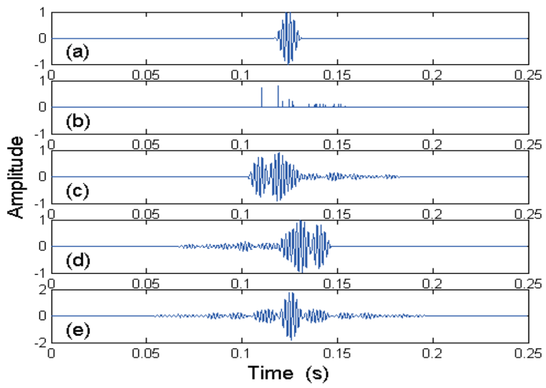

Fig. 1. Waveforms by TRA process. (a) emitted signal, *e(t)*, (b) impulse response, *h(t)*, (c) received signal, *s(t)*, (d) time reversed signal *r(t)*, (e) TRA focused signal, *c(t)*.

bkchoi@kordi.re.kr

To solve easily the convolution, we can use the Frourier transformation in frequency domain as

$$S(w) = E(w)H(w) \quad (3)$$

where *S(w)*, *E(w)* and *H(w)* are the Fourier transformation of *s(t)*, *e(t)* and *h(t)*, respectively.

Therefore, the Fourier transformation of the focused signal, *C(w)* is given by

$$C(w) = R(w)H(w) = S(w)^{*} H(w) \quad (4)$$

where *C(w)* and *R(w)* are the Fourier transformation of *c(t)* and *r(t)*, respectively.

3. Simulation of Impulse Response in the Rectangular Room

Let us consider the two-dimensional rectangular room as shown in **Fig. 2**.

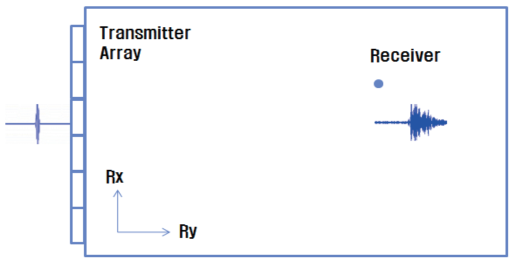

Fig. 2. Schematic diagram of rectangular room for TRA simulation.

In a rectangular room, the image sources can be indexed by integer coordinates *l*, *m*, and *n*, where (*l; m; n*) = (*0; 0; 0*) corresponds to the direct source, (*1; 0; 0*) corresponds to the first reflection in the positive x direction, and so on.

Given a room of size ($L_x; L_y; L_z$) with origin at the center and a source location ($S_x; S_y; S_z$), the image source location with indices (*l; m; n*) is

$$(I_X, I_Y, I_Z) = \{lL_X + (-1)^l S_X, L_Y + (-1)^m S_Y, lL_Z + (-1)^n S_Z\} \quad (5)$$

Then the distance d_{lmn} from the image source to the receiver at ($R_x;R_y;R_z$) is

$$d_{lmn} = \sqrt{(R_X - I_X)^2 + (R_Y - I_Y)^2 + (R_Z - I_Z)^2} \,. \quad (6)$$

The impulse response predicted by the image source method is

$$h(t) = \sum_{l,m,n=-\infty}^{\infty} \frac{\Re^{|l|+|m|+|n|}}{d_{lmn}} \delta(t - \tau_{lmn}) \qquad (7)$$

where $\tau_{lmn} = d_{lmn}/v$ is the wave propagation time from the image source at *(l; m; n)* to the receiver, v is the speed of sound, and $\Re$ is the reflection coefficient of the walls. Eq.(7) assumes that all surfaces have the same reflection coefficient.

Figure 3 shows the simulated impulse response with various reflections.

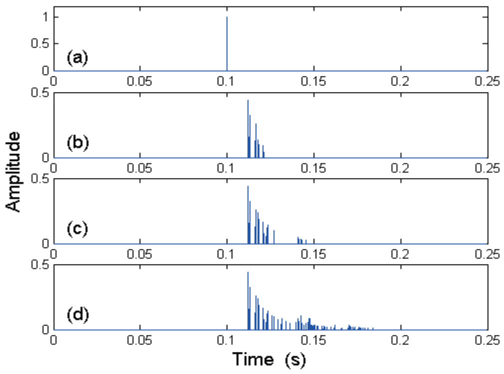

Fig. 3. Simulated impulse response using impulse signal in the rectangular room. (a) emitted impact signal, (b) received signal with 1st reflection, (c) received signal with 3rd reflections, (d) received signal with 10th reflections.

4. Results of TRA Simulation

Figure 4 shows the increasing effect of the amplitude with the number of transmitters.

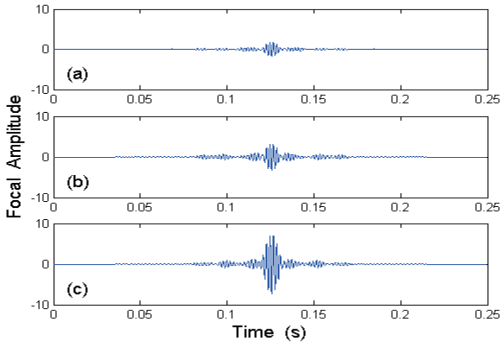

Fig. 4. Change of TRA focusing signal on the number of transmitter. (a) one transmitter, (b) two transmitters, (c) five transmitters.

Figures 5 and 6 show the spatial distribution of pressure amplitude on x and y-axis, respectively. The maximam amplitude position is the focal region. To increase the number of transmitter is to improve the performance of focusing.

The standing wave effect along the x-axis is shown in **Fig.5**.

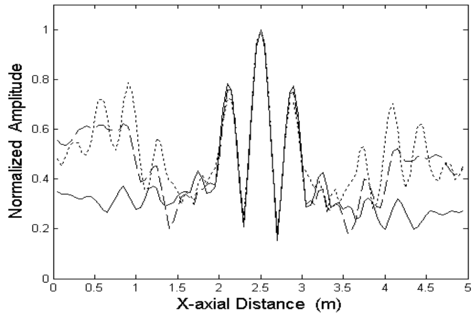

Fig. 5. Spatial distribution of pressure amplitude on x-axis (solid line: one transmitter, dotted line: two transmitters, thick solid line: five transmitters).

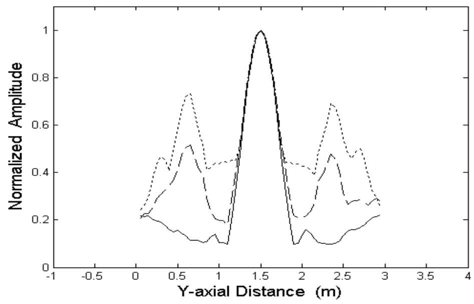

Fig. 6. Spatial distribution of pressure amplitude on y-axis (solid line: one transmitter, dotted line: two transmitters, thick solid line: five transmitters).

4. Conclusion

We confirmed the impulse response simulation of rectangular room. From this simulation, we got good results of TRA focusing. According to increase the number of source, the focusing effeciency is increased.

Acknowledgment

This work was supported by the projects "A study of underwater acoustic field reconstruction using time reversed method" (PE9853C) and "A study on variability in coastal environment of the East Sea" (PE98444) at Korea Ocean Research and Development of Institute (KORDI).

References

1. M. Fink, Scientific American, November, 91 (1999).
2. M. Fink, D. Cassereau, A. Derode, C. Prada, P. Roux, M. Tanter, J. Thomas, and F. Wu, Reports on Progress in Physics 63, (2000) 1933.
3. A.M. Sutin and P.A. Johnson, Review of Quantitative Nondestructive Evaluation edited by D. O. Thompson and D. E. Chimenti (AIP, New York), 24, (2005) p.385.
4. A. Sutin and A. Sarvazyan, Proceeding of the World Congress on Ultrasonics, Paris, September, (2003) 863.
5. H. C. Song, W. A. Kuperman, T. Akal and C. Ferla, J. Acoust. Soc. Am. 105(6), (1999) 3176.
6. Bowon Lee, Mark A. Hasegawa-Johnson, and Camille Goudeseune, J. Acoust. Soc. Am. 113, (2003) 2202.