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Acoustic source localization in non-homogenous plates

Shenxin Yin[a,b], Zhiwen Cui[a*], Tribikram Kundu[b*]
[a]Dept. of Acoustics and Microwave Physics, College of Physics, Jilin University, Changchun, Jilin 130012, China; [b]Dept. of Civil and Architectural Engineering and Mechanics, University of Arizona, Tucson, Arizona 85721, USA
cuizw@jlu.edu.cn; tkundu@email.arizona.edu

ABSTRACT

In a nonhomogeneous specimen, if the acoustic source and receiving sensors are located in different media then the acoustic source localization becomes very difficult. In this paper, a recently developed source localization technique is extended to non-homogeneous plates by appropriately considering and modeling the refraction phenomenon. The modified technique is applied to two-layered structure. The proposed new technique gives a relatively simple way to localize the acoustic source without the need to solve a system of nonlinear equations, and thus it avoids the problem of multiplicity, converging to local minima instead of global minimum and giving wrong solution. The proposed technique works for both isotropic and anisotropic structures. The finite element simulation shows that this modified technique considering refraction at material interfaces can localize the acoustic source better than when this modification is not considered.

Keywords: Source localization; Refraction; Multilayered media; Time difference of arrival

1. INTRODUCTION

Several techniques have been proposed and work very well for acoustic source localization in a homogeneous plate. However, for a non-homogeneous plate, the process of acoustic emission source localization becomes more difficult, especially when the acoustic source and receiver sensors are in different media. This is because when the acoustic signals propagate from one material to another then their propagation paths deviate from a straight line path due to refraction occurring at the interface of the two materials. Kundu et al.[1,2] proposed an acoustic source localization technique to localize acoustic sources in plates without knowing the plate properties works well for homogeneous plates. However, it fails to localize sources in nonhomogeneous plates that contain interfaces. When the acoustic signal propagates through different media in a nonhomogeneous plate, it is refracted at the interfaces following Snell's law. In this paper the technique from Kundu et al.[3,4] is modified considering the refraction effect. The modified technique is applied to two-layered plates. Using finite element simulation the acoustic emission in a structure made of two materials was modeled. The results show the superiority of the proposed technique.

2. FORMULATION

The new right-angle configuration of a sensor cluster proposed by Kundu et al.[2,5] is composed of 3 sensors mounted orthogonally with a constant distance *d* from the middle sensor S_1 to the end sensors S_2 and S_3 in orthogonal directions, as shown in Figure 1. The coordinates of sensors S_1, S_2 and S_3 are (x_1, y_1), (x_2, y_2) and (x_3, y_3), respectively. It is clear that $x_1 = x_2 + d$, $y_1 = y_2$, $x_3 = x_1$ and $y_3 = y_1 - d$. The ratio of TDOAs (time difference of arrivals) between two pairs of sensors

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(S_1-S_2 and S_1-S_3) gives the direction of the plane wave front which is also the straight line drawn from the acoustic source to sensor S_1.

$$\tan\alpha_1 = \frac{\Delta t_{13}}{\Delta t_{12}} \tag{1}$$

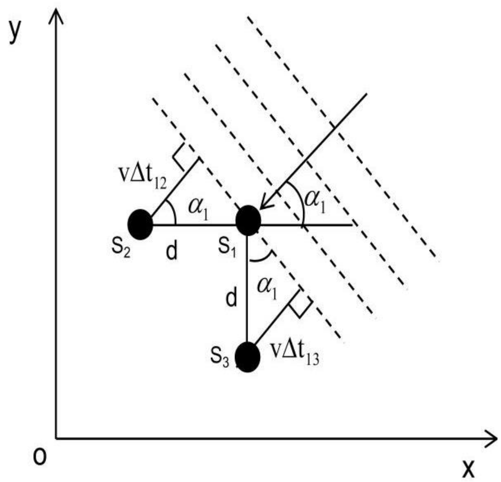

Figure 1. The sensor cluster is placed on the surface of the plate to record the arriving wave signals.

2.1 Acoustic source localization in non-homogenous plates with known velocity

Figure 2 (left diagram) shows the true propagation paths of the waves from the acoustic source to the sensors clusters. The right diagram of Figure 2 shows two sets of approximate paths. Dotted lines show the paths without considering the refraction and assuming the acoustic speed to be the average velocity of two different media.

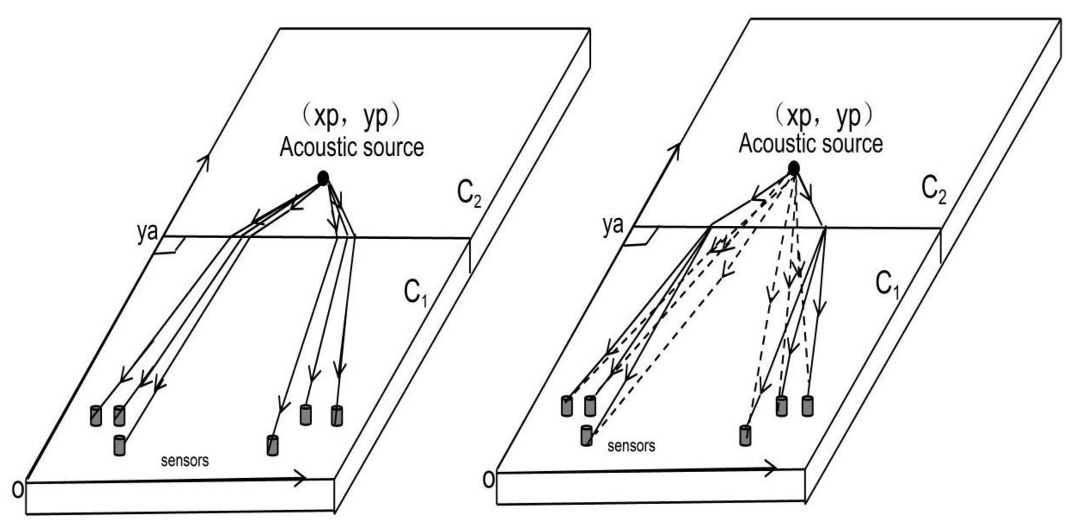

Figure 2. The true propagation paths (left) and two sets of approximate paths (right). One is average velocity method without considering refraction (dotted lines). The other one is the new technique that considers refraction (solid lines).

When acoustic waves travel from one medium to another, they refract at the interface following Snell's law. As shown in Figure 3, the coordinate of acoustic emission source P is (xp, yp). The distance between the sensor clusters and interface should be known. That means the height of interface ya is known. So it is easy to find the intersection coordinates (xa, ya) of the interface.

$$\mathrm{xa} = \frac{(\mathrm{ya} - \mathrm{y}_1)}{\tan \alpha_1} + \mathrm{x}_1 \tag{2}$$

θ_1 can be expressed by the time difference of arrivals (TDOAs) between sensors S_1 and S_2.

$$\sin\theta_1 = \frac{\Delta t_{12} c_1}{d} \tag{3}$$

From the TDOA values in one sensor cluster the acoustic wave speed c_1 can be obtained. So one only needs to know either the other wave velocity c_2 or the ratio c_1/c_2. The acoustic wave velocity c_1 is obtained from the TDOAs using the following equations.

$$c_1 = \frac{d}{\sqrt{t_{12}^2 + t_{13}^2}} \tag{4}$$

Using Snell's law

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{c_1}{c_2} \tag{5}$$

θ_2 can be evaluated.

$$\sin\theta_2 = \frac{\Delta t_{12} c_2}{d} \tag{6}$$

The direction of the propagating acoustic wave then can be written as

$$\tan\alpha_2 = \sqrt{\frac{d^2 - (\Delta t_{12} c_2)^2}{(\Delta t_{12} c_2)^2}} \tag{7}$$

A line through the acoustic source could be expressed by the time difference values of one cluster and some space information after considering refraction. One more line through the acoustic source can be obtained in the same manner from a second cluster. Accuracy of the prediction can be checked and improved by adding more sensor clusters.

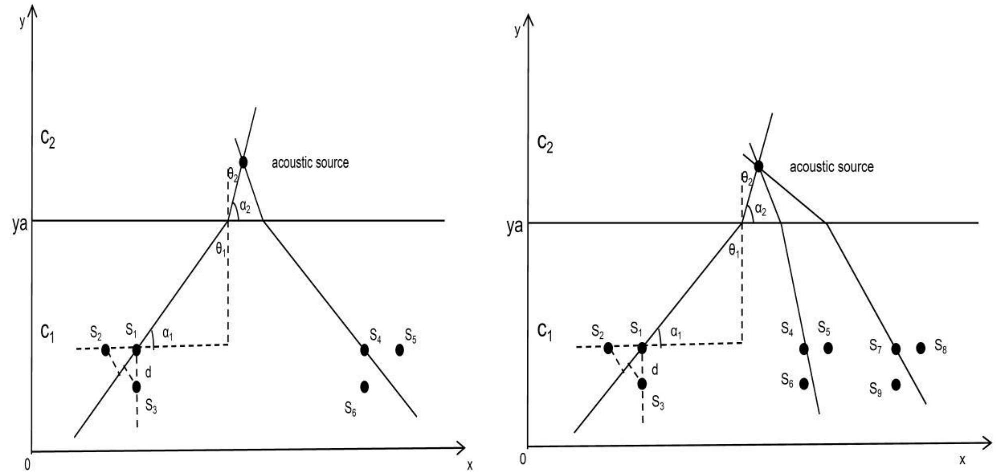

Figure 3. Two clusters give two lines considering refraction. The intersection of two lines indicates the predicted acoustic source position as shown in the left diagram. The third cluster will give the third line to confirm the localization accuracy as shown in the right diagram.

2.1 Acoustic source localization with unknown wave velocity

When the wave velocities in all media are unknowns, the acoustic source can also be predicted by placing receiving sensor clusters in all media as shown in Figure 4. The acoustic wave velocity in any medium can be obtained from the time difference of arrival values in that cluster similar to Eq. (4). The other direction can be obtained from the time difference values in the other cluster. The point of intersection of the two lines is the acoustic source location as shown in Figure 4.

$$c_2 = \frac{d}{\sqrt{t_{45}^2 + t_{46}^2}} \tag{8}$$

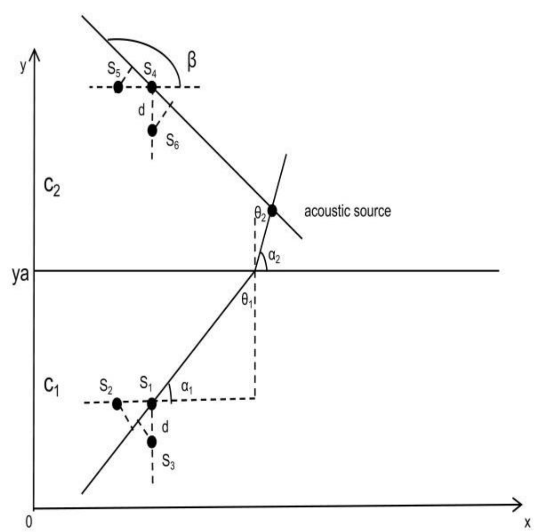

Figure 4. When the velocity values are unknowns the acoustic source can be predicted by putting receiving sensor clusters in the both media.

3. FINITE ELEMENT SIMULATION

A two-dimensional finite element model for propagation of ultrasonic waves in fluid and solid media was developed and analyzed by COMSOL. The two-dimensional model was 500 mm x 500 mm in size. The acoustic velocity in upper part is 1500 m/s. The lower part is another medium whose acoustic wave speed is 3000 m/s. A Gaussian pulse was used as the acoustic emission source. The coordinate of the acoustic source (xp, yp) was changed to verify the technique for various source locations.

The probes are placed as receiving sensors at the appropriate coordinates for the sensor clusters. The time differences can be obtained easily comparing the corresponding peak positions. All receiving sensors are placed in the same medium. The results of WOR (or without refraction) results are obtained assuming homogeneous medium and without considering any refraction at the as interface shown in Table 1.Then the same acoustic sources are localized by two other techniques WR (or with refraction) and WR&U as a comparison. WR&U results are obtained when 2 sensor clusters are placed in 2 different media, so that sources can be localized without knowing the wave speeds in either medium. The absolute error is shown in Table 1. The results show that all three methods cannot predict the acoustic emission source accurately. WOR results are not very reliable.

Table 1. Results from all three methods (WOR, WR and WR&U).

Actual AE source		Predicted AE source								
		WOR			WR			WR&U		
xp	yp	x	y	error	x	y	error	x	y	error
25	28	25.03	26.16	1.84	24.98	27.66	0.34	25.14	27.99	0.14
25	30	24.99	26.86	3.14	25.02	29.3	0.7	25.35	30.61	0.71
18	30	18.41	26.68	3.34	18.57	29.51	0.75	18.67	30.03	0.67
30	30	29.76	26.77	3.24	29.59	29.28	0.83	30.24	30.83	0.86

4. CONCLUSION

In this paper the source localization technique is extended to the non-homogeneous structures considering the refraction phenomenon. The finite element simulation is carried out to validate the proposed technique. The advantages of the proposed technique can be listed as follows:

(1) No complicated nonlinear equation solution is required which avoids the problem of multiplicity and wrong solution. The process of acoustic emission source localization is fast and easy for structural health monitoring.

(2) Only six sensors will give two lines for acoustic emission source localization considering refraction (WR) in a non-homogeneous plate made of two materials.

(3) The new technique works even when the wave velocities in different layers are unknown.

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