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Sound localization in an anisotropic plate using electret microphones

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ABSTRACT

Acoustic source localization without knowing the velocity profile in anisotropic plates is still one of the most challenging areas in this field. The current time-of-flight based approaches for localization in anisotropic media, are based on using six high sampling sensors. The number of sensors and the corresponding large amount of data, would make those methods inefficient in practical applications. Although there are many different non-time-of-flight based approaches such as machine learning, or soft computing based methods that can be used for localization with a less number of sensors, they are not as accurate as time-of-flight based techniques.

In this article, a new approach which requires only four low sampling rate sensors to localize acoustic source in an anisotropic plate is proposed. In this technique, four electret low sampling rate sensors in two clusters are installed on the plate surface. The presented method uses attenuation analysis in a suitable frequency band to decrease the number of sensors. The approach is experimentally tested and verified on an airplane composite nose by applying artificially generated acoustic emissions (Hsu–Nielsen source). The results reveal that the accuracy of proposed technique depends on distinction of dominant frequency band. A stethoscope as a physical filter is employed to reduce the sensitivity of the technique and delineation of frequency band. The suggested technique improves the accuracy of localization prediction.

1. Introduction

Acoustic source localization in a plate is commonly known as the process of locating acoustic sources by analyzing the transient elastic wave propagated through the plate [1]. This is a vital step in Structural Health Monitoring (SHM) systems. The elastic waves can be generated under two modes: active, such as acoustic actuators in ultrasonic inspection and passive such as impacting external object in acoustic emission (AE) monitoring [2]. Several methods have been proposed in the literature to find the location of external source in passive mode by analyzing the data. The most common method for source localization is the triangulation technique that has been developed by Tobias [3]. Kundu [1] presented a comprehensive review of source localization, the article classified the techniques according to whether the medium is isotropic or anisotropic. Note that all the techniques presented for anisotropic are applicable for isotropic medium, as well. Most of these methods are performed in two steps: (1) determining the time difference of arrival (TDOA) between sensors and (2) solving the system of nonlinear equations [4,5] and optimizing an error function [6–9], or providing a probabilistic framework based on nonlinear Kalman Filtering methods [10–13]. Other procedures reported in the literature are based on time reversal methods [2,14–16], soft computing [17] and Gaussian process [18]. Knowing the velocity profile of anisotropic plates limits the extension of acoustic source localization in industrial area. Therefore, researchers prefer to use techniques in which there is no need to know the plate properties (such as direction dependent velocity profile).

Among research studies on anisotropic media, two are independent of plate properties, presented by Ciampa et al. [4] and Kundu [19,20]. Although there are no preferences in number of sensors (both techniques need at least six receiving sensors), in contrast to the method presented by Ciampa et al., the Kundu technique localized acoustic source without any need to solve a system of nonlinear equations [1]. In both research studies the distances between sensors in the cluster are assumed to be much smaller than the distances between acoustic sources and each sensor. Hence, the assumption of same group speeds for the sensors in the same cluster seems to be reasonable. Note that, in time-of-flight based methods without using the aforementioned assumptions acoustic source localization in plates with unknown velocity profile due to indeterminacy problem is almost impossible. The major drawback of these techniques is the high

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Nomenclature

SHM	structural health monitoring
TDOA	time difference of arrival
AE	acoustic emission
t	time
C	wave travel velocity
d	distance between sensors
D	distance between source to each sensors

Greeks

θ	direction

Subscripts

P	acoustic source

computational cost of the algorithms because of the number of sensors and use of high sample rate data.

In this paper, an acoustic source was localized in anisotropic plate where the velocity profile is unknown and only four receiving low sampling rate data are available. In the proposed method, two clusters of sensors (each cluster containing two sensors) were used. Finally, the proposed technique is verified by an experiment on an airplane nose. The main advantage of the presented method in comparison with other established techniques is exploiting four sensors instead of six, using low sampling rate data.

The layout of this paper is as follows. Section 2 presents the problem description. The formulation and required materials are presented in Section 3. Section 4 reports the experimental set-up. Results and discussion are rendered in Section 5 and finally concluding remarks are summarized in Section 6.

2. Material and methods

2.1. Problem statement

For simplification, the methods presented by Ciampa et al. [4] and Kundu [19,20] are mentioned as *CIMEO* and *KUNDU* methods, respectively. These techniques are considered as the most efficient time-of-flight based methods in acoustic source localization because these techniques can be implemented in anisotropic plates without knowing material properties. To get a better vision of these techniques the similarity and differences between these two techniques are discussed as follows.

2.1.1. Similarity

The similarity can be classified into three classes. (1) Equipment requirement: both methods used six acoustic sensors with the central frequency of 300 kHz. (2) Technique: it used a cluster of sensors instead of using sensors individually. The distances between clusters are known. Correct estimation of TDOA plays a major role in the final prediction. Both techniques work only for a single acoustic source at a time. (3) Assumptions: The distances between sensors (d) are assumed to be much smaller than the distance between sensors and the acoustic source (D).

2.1.2. Differences

Similar to previous classification, the following were done. (1) Equipment requirement: in *CIMEO* technique, acoustic PZT (lead zirconate titanate) and in the *KUNDU* method R-Cast contact type compressional AE sensors were used. (2) Technique: *CIMEO* method used 3 clusters of sensors; each cluster contains two sensors while 2 clusters were used in the *KUNDU* method; and each cluster contains three sensors. Time of Arrivals (TOA) of the lamb wave was estimated by wavelet transform in *CIMEO* method, while TOA was calculated using cross correlation in *KUNDU* technique (Lamb waves are elastic waves propagating in thin plate-like structures; readers are referred to [21] for details). In other words, the TOA estimation in *CIMEO* and *KUNDU* methods is based on Time-Frequency and Time domain specifications, respectively. In *CIMEO* method, the location of acoustic source was predicted by solving a nonlinear system of equations relating all the six sensors together, while in *KUNDU* technique each cluster of sensors specifies straight lines with predicted inclination angles which should intersect with each other at the acoustic source point. (3) Assumption: Although in both methods effect of reflected waves from edges was not considered at first, the KUNDU technique was improved by considering the effect of reflected wave and changing the distance d, considered by the authors in their another publication (Nakatani et al. [22]).

Considering the above conditions, it can be said that localization of the acoustic source (with unknown velocity profile in anisotropic plates) using both lower number and lower sample rate sensors presented in this article is a significant achievement in extension of the method to industrial applications.

3. Formulation

Four acoustic sensors $S_i(i = 1, 2, 3, 4)$ are attached on the surface of an anisotropic plate in two different clusters (see Fig. 1). The coordinates of sensors and unknown acoustic source are (x_i, y_i), $i = 1, 2, 3, 4$ and (x_p, y_p), respectively. The distance between sensors in the same cluster is d, while the distance between acoustic sources from each sensor is $D_i(i = 1, 2, 3, 4)$, illustrated in Fig. 1. Similar to previous studies [4,22] the distance d should be much smaller than D_i ($D_i \gg d$) to consider the same profile speed for sensors in each cluster. So the inclination angle of θ_i, $i = 1, 2$ (see Fig. 1) assumed to be almost the same. These assumptions can be expressed as follows:

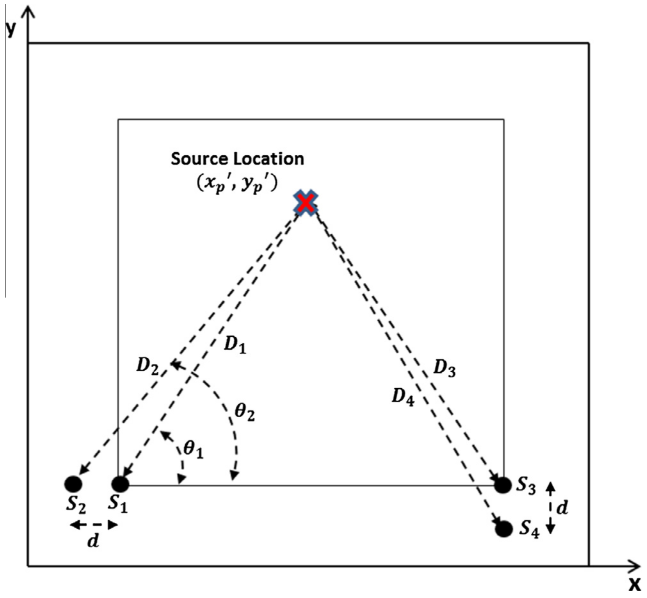

Fig. 1. Acoustic source and two clusters containing two sensors each.