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Acoustic source localization

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ABSTRACT

In this article different techniques for localizing acoustic sources are described and the advantages/disadvantages of these techniques are discussed. Some source localization techniques are restricted to isotropic structures while other methods can be applied to anisotropic structures as well. Some techniques require precise knowledge of the direction dependent velocity profiles in the anisotropic body while other techniques do not require that knowledge. Some methods require accurate values of the time of arrival of the acoustic waves at the receivers while other techniques can function without that information. Published papers introducing various techniques emphasize the advantages of the introduced techniques while ignoring and often not mentioning the limitations and weaknesses of the new techniques. What is lacking in the literature is a comprehensive review and comparison of the available techniques; this article attempts to do that. After reviewing various techniques the paper concludes which source localization technique should be most effective for what type of structure and what the current research needs are.

Contents

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1. Introduction

Acoustic source can be of various kinds – (1) impact of a foreign object, (2) crack formation, such as matrix cracking and delamination in a composite material, and (3) structural element failure, such as cable failure in a bridge or failure of rebars in reinforced and prestressed concrete, or fiber breakage in a composite material. All these events generate acoustic waves. The process of locating the source of these acoustic waves, by recording the propagating acoustic signals by various sensors and properly analyzing them, is commonly known as the *acoustic source localization* technique. It is an important step for *structural health monitoring* (SHM).

Two components of SHM that have received significant attention from the research community are *Diagnosis* and *Prognosis*. During the diagnosis stage the damage is characterized – its location, size and orientation are measured to get an idea about the severity of the damage. Nondestructive testing and evaluation (NDT&E) is used at the diagnosis stage then the remaining life of the structure is estimated during prognosis. Knowledge of fracture mechanics and fatigue crack growth is necessary for predicting the remaining life of the structure under certain loading conditions.

For large structures it is not possible to inspect every part of the structure very carefully at the diagnosis stage; therefore, one needs to focus on certain regions of the structure that are more susceptible to damage initiation. These regions are commonly known as *hot spots*. Regions that are subjected to high levels of stress constitute the hotspot regions. However, sometimes the hot spot regions in a large plate or shell type structure cannot be predetermined. For example the wing and the fuselage of an airplane or the outer surface of a space shuttle can have damage initiated at any point if it is struck by a foreign object, such as the space junk or debris striking the space shuttle, a flying bird hitting the airplane fuselage, or a tool dropping on the airplane wing. After any such hit the structure should be inspected near the impact region. Therefore, this region must be identified by the acoustic source localization technique. Then more careful inspection of that region can be carried out to conclude if any significant damage occurred there.

Critical structures made of composite materials need to be monitored continuously not only for detecting the point of impact of a foreign object but also for monitoring matrix cracking, fiber breakage and inter-laminar delamination. Ultrasonic transducers are used for this purpose. For monitoring structural damage ultrasonic transducers can work in two modes – *active* and *passive* modes [1]. Under active mode acoustic actuators generate ultrasonic signals [2] and under passive mode the impacting foreign objects or crack initiation and propagation act as the acoustic source [3,4]. Ultrasonic sensors are placed on the structure to efficiently receive ultrasonic signals from the acoustic source and monitor its condition [5–10].

This paper reviews the passive monitoring techniques used for acoustic source localization in isotropic and anisotropic structures. Early works on source localization were carried out by Tobias for isotropic structures [11] and by Sachse and Sancar [12] for anisotropic structures. Earlier attempts of locating the acoustic emission sources in anisotropic plates required the measurement of two dominant pulses in a waveform whose speeds of propagation, c_1 and c_2 were known, and the receiving sensors were to be placed as a sensor-array – on the periphery of a circle or on two orthogonal lines [12]. Other restrictions of the earlier analyses are [13], (1) the order of the elastic symmetry of the solid is to be orthorhombic or higher, (2) the principal axes of the solid are to be known *a priori* and to be oriented along the coordinate axes of the specimen, and (3) the sensors comprising the receiving array must be placed on principal planes of the material. The last constraint condition may not be satisfied for single-crystal specimens that have been cut in an arbitrary orientation. Although the first constraint condition is approximately satisfied for most engineering materials it may not be true in some cases. Even the widely used engineering materials such as the fiber reinforced composite solids may violate this condition. Note that although fiber reinforced composite solids are often assumed to be orthotropic or transversely isotropic materials the non-uniform distribution of fibers may not make *xz, yz* or *xy* planes of the *xyz* coordinate system to be planes of symmetry. Readers are referred to Cowin and Mehrabadi [14] for definitions of different types of symmetry and principal planes of symmetry.

Since these earlier works many techniques for source localization have been proposed. These newer methods are reviewed here. Advantages and disadvantages of the proposed methods are discussed and which methods should be most efficient for solving a specific class of source localization problems are suggested – starting with simple isotropic structures and ending with anisotropic structures with complex geometry.

2. Source localization in isotropic plates

2.1. Triangulation technique for isotropic plates with known wave speed

Triangulation technique [11] is the most popular source localization technique for isotropic and homogeneous structures. This

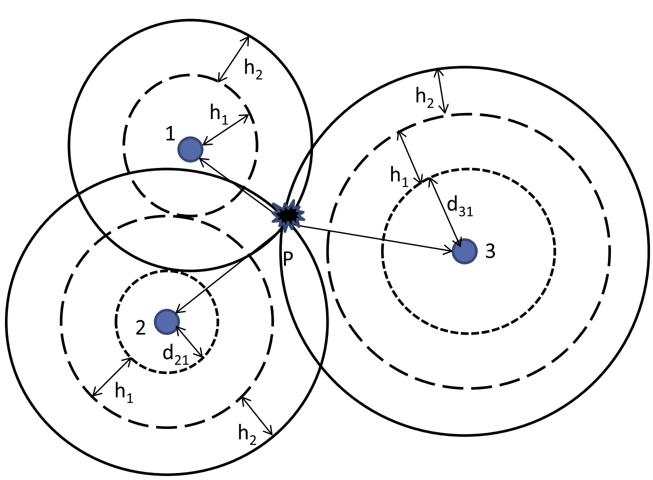

Fig. 1. Triangulation technique – three sensors placed at positions 1, 2 and 3 receive the acoustic waves generated by the source at position P. Radius of each circle corresponds to the distance traveled by the wave from the source to the sensor.

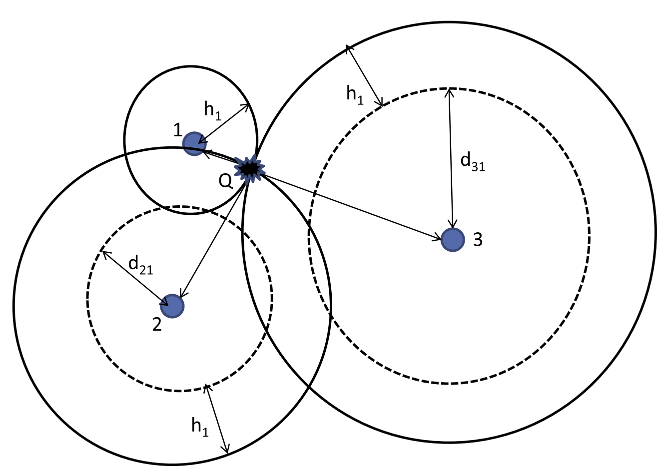

Fig. 2. Triangulation technique – similar to Fig. 1 but in this figure the wave speed in the plate is twice of that for Fig. 1 resulting a different location of the acoustic source for the same difference of time of flights for the three sources.