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Determination of the probability zone for acoustic emission source location in cylindrical shell structures

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A B S T R A C T

This paper presents a probabilistic framework for acoustic emission (AE) source localization in cylindrical structures. Specifically, an approach based on unscented transformation (UT) is proposed to take into account uncertainty in time of flight measurements and wave velocity and eventually estimate AE source locations together with quantitative measures of confidence associated with those estimates. Experiments are carried out on a steel pipe instrumented with an array of six embedded piezoelectric disks. Results are compared with Monte Carlo simulations by the Kullback–Leibler divergence.

1. Introduction

Engineering structures such as pipelines, pressure vessels, and aircrafts are made of thin-walled shells whose performance and functionality is essential. Presence of defects, such as fatigue cracks, corrosion, impacts, in shell structures may severely compromise the overall soundness of these structures. Therefore, their proper assessment is crucial. To minimize the maintenance costs and to increase the operation lifetime, researchers and practitioners are increasingly interested in building advanced structural health monitoring (SHM) strategies [1]. In particular, SHM strategies based on acoustic emissions (AE) have been widely used [2–9] in the last three decades. In general, AEs are stress waves produced by sudden strain releases due to internal fractures [10]. A burst of energy can be released in the form of high-frequency sound waves from propagating cracks or from plastic deformations if a material is overstressed. Conventionally, an array of piezoelectric transducers is attached to the structure of interest to detect these waves and triangulation techniques are used to perform the critical task of damage localization [11–15]. These techniques work very well when the wave velocity (V) in the test material and the arrival time (t_i) of the wave at all sensor locations is known. For example, considering an array of three sensors on the surface of a thin cylinder, the AE source can be identified by drawing three circles of radii (R_i), whose centers coincide with the three sensor locations, as shown in Fig. 1a. The radius R_i is the shortest path connecting the AE source and each sensor and it can be obtained by multiplying the time of arrival of the wave (t_i) with the wave velocity (V). However, in real life, time of arrival measurements and wave velocity are in general affected by random and systematic errors. Random errors are caused by unknown and unpredictable changes in measurements, e.g. instrumentation noise. Systematic errors are mostly caused by the digital signal processing technique used for analyzing the time waveforms [16–18]. Therefore, rather than the damage being located at

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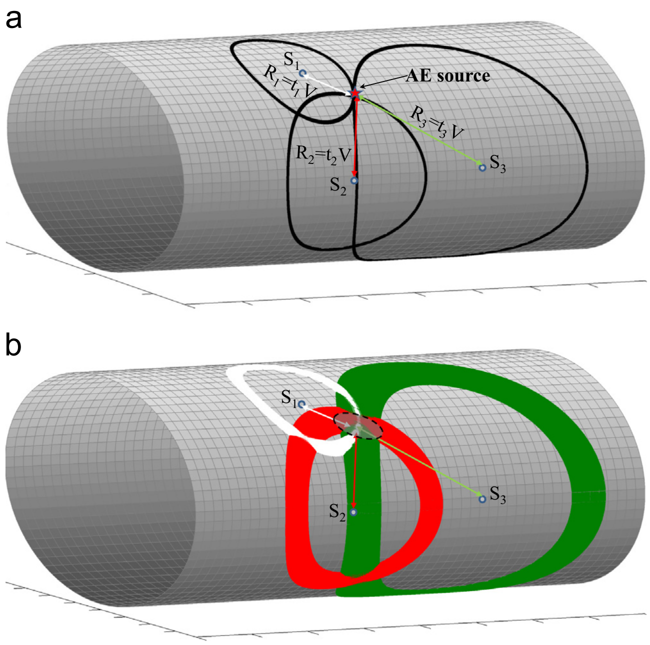

Fig. 1. AE Source localization using triangulation: (a) without uncertainty, (b) with uncertainty.

a single point (i.e., at the intersection of the circles as shown in Fig. 1a), the damage can be located anywhere in the dark overlapped region, as shown in Fig. 1b or it can remain undetected until failure of the structural system [19–21].

The ring's width represents the uncertainty in the measured distance as a result of measurements uncertainty (i.e., t_i and V). To consider these uncertainties, a probabilistic framework based on nonlinear Kalman Filtering techniques has been recently proposed by the authors for AE source localization in plate-like structures [16,19,20]. This framework is here extended to cylindrical shell structures. Specifically, an approach based on unscented transformation (UT) is proposed to take into account uncertainty in time of flight measurements and wave velocity and eventually estimate AE source locations together with quantitative measures of confidence associated with those estimates.

2. AE source localization in cylindrical shell structures

Let's consider a cylindrical structure instrumented with a sensor, and an AE source located on its surface, as shown in Fig. 2. It is known, that circumferential waves can propagate from the same source to the same sensor through infinite helical paths, as shown in Fig. 2a [13,22]. For structures with small wall thickness-to-diameter-ratio, these circumferential waves can be considered similar to Lamb waves in plates, by replacing the cylindrical structure with an equivalent "unwrapped" two dimensional plate [23]. Using the "unwrapped" representation, helical paths can be considered as a single AE source detected by multiple "virtual" sensors [13]. Assuming an arbitrary Cartesian coordinate system, the AE source is at the unknown coordinates (x_s, y_s), the sensor is located at (x_i, y_i), and the virtual sensors are placed at the vertically repeating positions, as shown in Fig. 2b. The distance between each pair of virtual sensors is πD, where D is the diameter of the cylinder [13]. Also indicated in Fig. 2, three possible helical paths, whose lengths, $l_0^i, l_1'i, l_1^i$, can be defined as:

$$l_0^i = \sqrt{(x_s - x_i)^2 + (y_s - y_i)^2} \tag{1a}$$

$$l_1'i = \sqrt{(x_s - x_i)^2 + (y_s - (y_i + \pi D))^2} \tag{1b}$$

$$l_1^i = \sqrt{(x_s - x_i)^2 + (y_s - (y_i - \pi D))^2} \tag{1c}$$

Conventionally, AE source localization is performed using time-of-flight (t) measurements taken at multiple receiving points. Particularly, given an array of n sensors, if t_m is the travel time of the first arrival waveform to reach the first triggered sensor (master sensor), and Δt_{mi} is the time difference between master sensor and the ith sensor, the following equations can be obtained:

$$l_{\min}^m - t_m V = 0 \tag{2}$$

$$l_{\min}^i - (t_m + \Delta t_{mi})V = 0 \tag{3}$$