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Fast and Reliable Acoustic Emission Source Location Technique in Complex Structures

***Safaa Al-Jumaili[1,2], Matthew Pearson[1], Karen Holford[1], Mark Eaton[1] and Rhys Pullin[1]**

[1]Cardiff School of Engineering, Cardiff University, Queen's buildings, The Parade, Cardiff, CF24 3AA, UK
[2]University of Basrah, Basrah, Iraq

*Al-JumailiSK@cardiff.ac.uk

ABSTRACT

Acoustic emission (AE) provides engineers with a powerful tool by allowing the location of damage sources as they occur. Damage localisation using traditional time of arrival approaches is inadequate in complex structure components. Cardiff University presented a novel approach known as Delta T mapping which overcame these limitations but it was considered as time consuming and an operator dependent approach. This paper presents new full automatic Delta T mapping technique overcomes these remaining limitations.

Keywords: *acoustic emission; source location; complex structure; unsupervised clustering; Delta T technique*

1. Introduction

Damage localisation in complex structures, such as those found in aerospace applications, is a difficult problem in the field of structural health monitoring (SHM). The development of an easy to use, fast to apply, cost-effective and very accurate technique is key for the uptake of SHM. The use of Acoustic Emission (AE) [1] is important for SHM as it offers the potential for the real time monitoring of the health of a structure. Acoustic emission (AE) arising from damage mechanisms and propagating through the structure in the form of Lamb waves can be detected using piezoelectric sensors mounted on the surface of the structure. The ability to track the early onset of damage and hence determine the structure's integrity will enable the switch from periodic inspections to a more condition based approach, therefore enabling increased inspection intervals, reducing structure downtime and maintenance costs.

The time of arrival (TOA) technique is traditionally used to locate these sources, and relies on the assumption of constant wave speed within the material and uninterrupted wave propagation path between the damage and the sensor. In reality, structural complexities such as holes and thickness changes that may be present, which alter the wave propagation path and velocity. In order to overcome these limitations, Cardiff University developed a technique (called Delta T Mapping [2]) to locate damage in complex structures with high accuracy [3-5] by using artificial sources on an area of interest to create training maps. These maps are used to locate subsequent AE events arising from damage events. However, this technique needs high operator expertise to deal with the training map data (e.g. selecting the correct data) which can be a time consuming process as well as it requires the cluster diameter value to be identified in advance to be able to calculate the source location (only the convergence points inside a specific cluster diameter are used to calculate the probable AE source location). The most recent version of Delta T technique is known as the AIC Delta T Mapping technique and was developed by Pearson et al [6, 7] and overcame the limitation of arrival time calculation, another source of error in the traditional approach.

In this paper, a new and improved fully automatic Delta T Mapping technique is present. Here the correct data in the training maps were identified and selected automatically using a clustering algorithm and a new approach (Minimum Difference approach) is used to determine the damage location. This paper reports experimental validation of the advantages of the new techniques achievements. The results showed excellent reduction in running time (from 7 hours to only 11 seconds) as well as improved accuracy (location error improved from 4.96mm to 3.88mm in a complex geometry).

2. Automatic Delta T mapping technique Methodology

This approach can be divided into two parts; firstly, selecting the valid events (to be used for creating the initial maps) at each grid point using an unsupervised clustering technique and secondly, calculating the AE source location using the Minimum Difference approach [1].

In the first part, after collection of the training data by applying H-N sources [8] (an artificial AE source) on each node position in the grid the time of arrival to each sensor is obtained using the AIC approach [9]. The classification process is applied at each grid position to select AE events which are highly similar to each other, where the input data vector for the clustering process is the time difference between sensors pairs and will be used for the similarity criteria by following these steps:

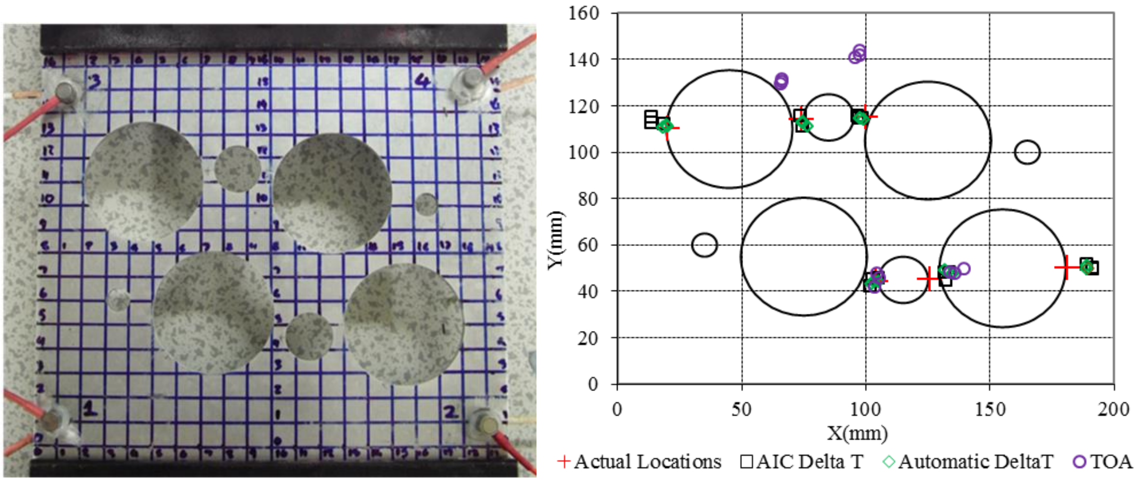
- In each point of the Delta T grid, the recorded hits were separated automatically to create AE events using a time based approach. Simultaneously, the incorrect erroneous data were automatically removed.
- The AE hits from each point within the delta grid are correlated with the point coordinates (x, y) automatically, using time stamps placed by the operator within the collected data. Where the time stamps are placed in the data following acquisition from each grid node and are then used to automatically identify which hits are associated with each grid node.
- Each event is identified by the calculated difference in time of arrival for each sensor pair (e.g. the case of four sensors creates six sensor pairs 1-2, 1-3, 1-4, 2-3, 2-4 and 3-4).
- A complete link hierarchical clustering algorithm [10] is then used to group events based on their similarity, or correlation coefficient. In this work the 0.99 correlation coefficient level from the largest group was selected and all events in this group were used (correlation coefficient of 1 means total correlation).
- Delta T maps from the average values of the difference in time of arrival for each sensor pair are calculated for the selected highly correlated events at each grid point.
- Calculate location of real AE data: the Minimum Difference approach is a numerical approach, which is dependent on finding the point at which the difference between the source data and the training map data is minimised.

3. Experimental Procedure

An aerospace grade 2024-T3 aluminium plate, with dimensions of 370 x 200mm with a thickness of 3.18mm was used to assess the performance of the new technique. The specimen contained a series of differing diameter circular holes as shown in Figure 1a. A MISTRAS PCI-2 system was used to record all AE data at 40 dB threshold and 2MHz sampling rate. Four MISTRAS Nano-30s were adhered on the front face of the specimen (Figure 1a) using silicon RTV (Loctite 595). All transducers were connected to MISTRAS 0/2/4 pre-amps which had a frequency filter of 20 kHz to 1MHz. The Delta T Mapping grid on the specimen covered an area of interest of 200mm x160mm and had a resolution of 10mm (Figure 1a). Five H-N sources were used at each node position within the grid. In order to assess the performance of the new Delta T mapping technique in a more complex structure, six arbitrary positions were selected within the Delta T grid and three H-N sources were conducted at each position. The average wave speed was calculated as 5400 m/s. Source locations were calculated using all four sensors using the traditional approach, Time of Arrival (TOA), AIC Delta T and the new Automatic Delta T for comparison.

4. Results and Discussion

Source location calculations using the AIC Delta T were conducted using 20mm cluster diameter (calculated using a trial and error procedure) and the training maps were filtered manually. For the Automatic Delta T source location calculations, the training maps are constructed automatically using the unsupervised clustering procedure. The source locations are then calculated using the Minimum Difference approach. Finally, the TOA location results were exported directly from the MISTRAS AEwin software. Figure 1b shows the source locations on the specimen from the three location methods.



(a) (b)

Figure 1: (a) Specimen Configuration (b) Calculated source location by three techniques

A comparison between the three methods results are provided in Table 1. From the table it's clear that the average error of the Delta T techniques is considerably lower than the TOA and offers an improvement in accuracy from 222 mm to approximately 5mm. As well as the automatic Delta T shows an improvement in accuracy over the AIC Delta T results by reducing the error from 4.96mm to 3.88mm.

Furthermore, there is significantly reduces the time invested in implementing the technique. The most time consuming step in the AIC Delta T is represented by the selection and preparing of the AE data to construct the training maps which takes approximately 7 hours. On the other hand, the Automatic Delta T mapping is very fast and reduces the running time for constructing the training maps to approximately 11 seconds which is a significant improvement. Moreover, the new Delta T does not require the trial and error process of determining the optimal cluster diameter when compared with the AIC Delta T the cost is approximately 3.6 hours.

Table 1 Techniques performance comparison

	TOA	AIC Delta T	Automatic Delta T
Average location error	222.18mm	4.96mm	3.88mm
One standard deviation of the average	±177.75mm	±3.14mm	±3.19mm
Prepare the AE data to construct training maps	-	25200 sec (7 hours)	10.88 sec
Calculate the optimal Cluster size	-	13089	0

5. Conclusions

A new fully Automatic Delta T technique is introduced and verified experimentally using a complex structure. The results obtained are excellent and demonstrate the success of the adopted methodology. The AIC Delta T technique has been improved, with this approach, considerably and has increased in processing speed, increased reliability, efficiency, more accurate, increased simplicity and more capability to apply in large scale structures.

The results of this study highlight the potential for the use of AE monitoring as a tool of SHM for damage localisation tasks; a high simplicity, fast, reliable, cheap and accurate technique has been presented. If this technique is integrated with commercial AE monitoring systems, it will be a powerful tool to provide real time highly accurate source location within complex large-scale components.

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