Application of Clustering Methods for Assigning Classes to Acoustic Signals

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***Abstract* – Evaluation of an acoustic emission waveforms acquired during structural health monitoring relies on the extraction and classification of features through the use of advanced digital signal processing. Trending of waveform features can permit the identification of damage types, propagation rate and severity. The analysis of trends within these extracted waveform features is often performed manually, possibly leading to inconsistencies in the information extracted. Accurate identification and assignment of classes is vital for the effective assessment of damage key characteristics of interest. The present study investigates the suitability of various clustering techniques with the aim of developing a fully automated system, which is independent of human input.**

***Keywords* –** *Acoustics Emission, Digital Signal Processing, Condition Monitoring, Structural Health Monitoring, Clustering*

I. INTRODUCTION

Fibre-reinforced composite (FRC) materials are increasingly used in marine environment and applications. Although such materials are corrosion resistant they are not straightforward to be inspected using conventional inspection methods particularly when they are in service. Structural Health Monitoring (SHM) techniques can be used for damage identification and characterisation in real time and while the structure is in service. Remotely Operated Vehicles (ROVs) and Autonomous Underwater Vehicles (AUVs) used for underwater exploration, ecological monitoring and sample collection, as seen within ENDURUNS and the upcoming MERLIN project, use FRCs for certain structural components thanks to the excellent mechanical properties the exhibit without concern for the occurrence of corrosion. Cyclical loading of these structures while in service and the possibility of damage initiation and subsequent uncontrolled propagation up to catastrophic failure make SHM particularly appealing for monitoring structural integrity and ensuring maintenance interventions are carried out timely.

Traditional means of inspection focus on use of non-destructive evaluation/testing (NDE/NDT) techniques such as ultrasonic testing (UT), thermography, radiographic testing, visual inspection etc. However, these techniques require direct access to the structure, often requiring its removal from operation, and only being able to detect damage present at the time of the periodic inspection. To address these limitations, acoustic emission (AE) monitoring can be employed, which allows for passive real-time monitoring of a structure during its operation. This allows for the direct identification of the occurrence of damage initiation within the material in real time. To achieve this, an automated procedure for establishing the trends present within the extracted information is required. Within the present study, we have focused on developing an automated intelligent methodology for the evaluation and characterisation of damage within structures using AE.

II. EVALUATION OF DAMAGE IN MATERIALS

To determine damage within a material using captured AE waveforms, extraction of key characteristic features must be completed through the implementation of digital signal processing (DSP) techniques. AE data acquisition during mechanical testing of fibre-reinforced composite (FRC) materials reported herewith, was completed using a custom-built AE system developed by researchers at the University of Birmingham (UoB). DSP was customised specifically for the evaluation of the AE signals acquired by the system.

For damage assessment using AE, several approaches and signal feature analysis can be employed. In this study, the assessment of the AE signals has been based on frequency components present in the acquired signals due to the consistency and reliability of the output. Frequency domain-based evaluation can assist towards identifying specific damage modes and is influenced to a lesser degree by external factors, particularly unrelated noise [1]. Frequency values identified can be directly related to a specific damage mode, each falling within a specific range within the frequency spectrum. Hence, DSP and feature assessment was focused upon the evaluation of peak frequencies associated with a particular damage event, helping establishing frequency bands associated with different damage modes in FRCs [2].

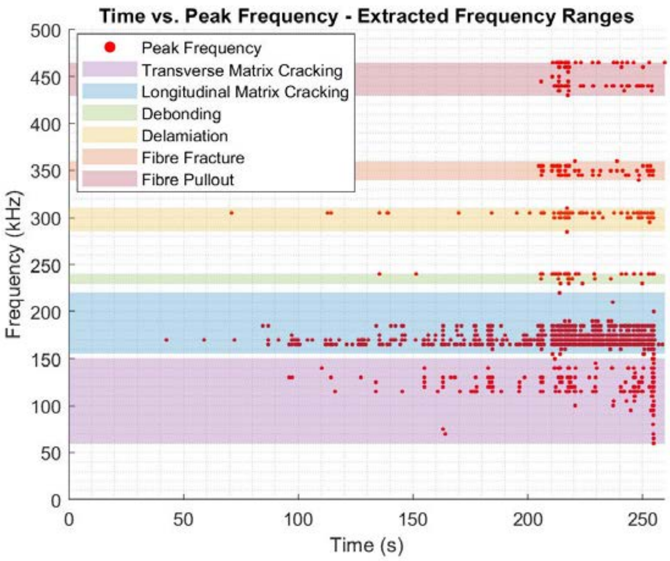

Figure 1: Example Peak Frequency vs. Time Plot Displaying Frequency Band Formation Arising from Occurrence of Specific Damage Modes

Figure 1 demonstrates clearly the presence of particular frequency bands within the generated representation of the DSP approach, visualising the logic behind the application of clustering techniques employed. Thus, frequency bands associated with particular damage modes in FRCs can be used to reliably cluster AE signals and accurately determine damage levels of the monitored structure.

III. EXPLORATION OF CLUSTERING TECHNIQUES

Within AE testing substantial effort has been dedicated to the use of k-means clustering. However, this particular approach has limitations. One of the key limitations in k-means clustering is the inconsistency in which the classes are assigned within an AE dataset. Furthermore, there is a requirement of some level of supervision regarding the definition of the number of clusters to be assigned [3].

Accurate identification of classes within a given dataset is needed to properly assess the damage mechanisms occurring at different stages of FRC structural degradation and confirm the severity of damage accumulation. Different mechanical tests or variations in FRC composition can generate different AE datasets, where it is not certain what the exact number of expected clusters will be in advance. Hence, the initial assignment of cluster ranges may lead to the misidentification of classes [4]. Additionally, this approach cannot be used when the sample behaviour is not entirely known in advance.

To mitigate these identified issues, alternative clustering techniques were tested and validated to assess their suitability and accuracy. The two methods which were considered as appropriate in mitigating the above issues were based on either Hierarchical Clustering (HC) or the Density-Based Spatial Clustering of Applications with Noise (DBSCAN) technique. Neither of these methods is entirely perfect. HC involves higher computational cost if a more accurate result is to be generated. Furthermore, it requires the selection of an appropriate linking method. Both HC and DBSCAN require the selection of distance measure dependent on the dimensionality and/or expected cluster shape [5]. However, the factors which influence selection of these parameters remain constant.

These various clustering techniques have proven successful for the evaluation and characterisation of damage mechanisms in FRC materials. However, there is an interest in achieving more accurate assessment of the damage severity in FRCs as well as other types of materials, such as metals and alloys.

Metals and alloys do not necessarily exhibit multiple damage modes like FRCs do. However, the reliable assessment of damage propagation rate and severity remains very important and desirable in determining the remaining lifetime of a structure as well as for planning maintenance interventions effectively.

IV. CONCLUSIONS

The accurate identification and assignment of classes to AE datasets acquired due to structural degradation of materials, including FRC, can enable the design of fully automated SHM systems. Such an automated system can use clustering of signals to identify specific damage events and potentially even quantify them, at least to some extent, without requiring direct input from an operator. This can allow the fast assessment of the health of the structure, determine the rate of degradation, and contribute towards the effective estimation of remaining lifetime. Nonetheless, stochastic parameters that can influence the above assessments have to be taken into consideration when trying to quantify the damage propagation rate, damage severity, and remaining lifetime of component.

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