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Impact localization on a composite stiffened panel using reference signals with efficient training process

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ABSTRACT

This paper suggests an efficient training process for estimating low-velocity impact locations on a composite stiffened panel using the reference signals. The reference signals were obtained from the fiber Bragg grating (FBG) sensor system suitable for on-board installation. Because such signals have low signal-to-noise ratio (SNR), they are not useful for most of previous studies with the time of arrival (TOA) or advanced signal processing. As the solutions to this weakness, the impact identification methods based on the reference database have been proposed. However, although some existing researches using the reference signals showed good localization performances, the training procedure to obtain the reference signals from much of training points is highly time-consuming. Aiming at this problem, an improved reference database impact localizing algorithm with reduced training points is presented in this article. To reduce the training points, the averaging signals with the adjacent reference signals are used as the imaginary reference signals of mid-points between each training points. As a result, the proposed algorithm could successfully estimate the impact locations within the allowable error bounds.

1. Introduction

The use of composite materials has consistently increased in various fields such as aerospace, automobile, civil structures and so on. Also, the portion of composite materials in the primary structure tends to exceed that of conventional metals. According to this trend, the secure of their reliability has become important as much as the improvement of their engineering properties. Among the shortcomings of composite materials to reduce their reliability, the susceptibility to internal damage caused by the low-velocity impact event is critical because such damage cannot be easily detected by traditional non-destructive inspection (NDI) methods. Moreover, the inspection area becomes broaden as the application region of composite materials increases. In order to improve such traditional damage evaluation methods, several researches [1–5] have been performed to develop more accurate and efficient NDI methods based on the images of ultrasonic propagations on the various structures. Also, acoustic emission (AE) and infrared thermography (IT) are widely used [6–10] for identifying and assessing various damages in composite structures. If these advanced NDI methods are cooperated with a real-time impact monitoring system, usefulness of a structural health management system can be dramatically enhanced. Thus, an on-board impact monitoring system is highly demanded for real-world applications.

There have been numerous researches about impact localization algorithms for metallic and composite structures with various sensor types. The mostly applied methods for impact localizations are the triangulation method [11–21], the neural network algorithm [23–26], the time reversal method [27–32] and the reference database method [33–35]. The conventional triangulation method showed some limitations for applying to anisotropic structures because the speed of impact-induced wave differs in all directions. Since then, a number of studies [17–20] have been performed to overcome the weakness of conventional triangulation methods, however, a priori information about impact-induced waves and target structure's properties is required for high-accuracy result. Recently, several papers [21,22] suggested the low-velocity impact localization methods using the time of arrival (TOA) between each signals and the location of sensors without any information of the impact-induced elastic

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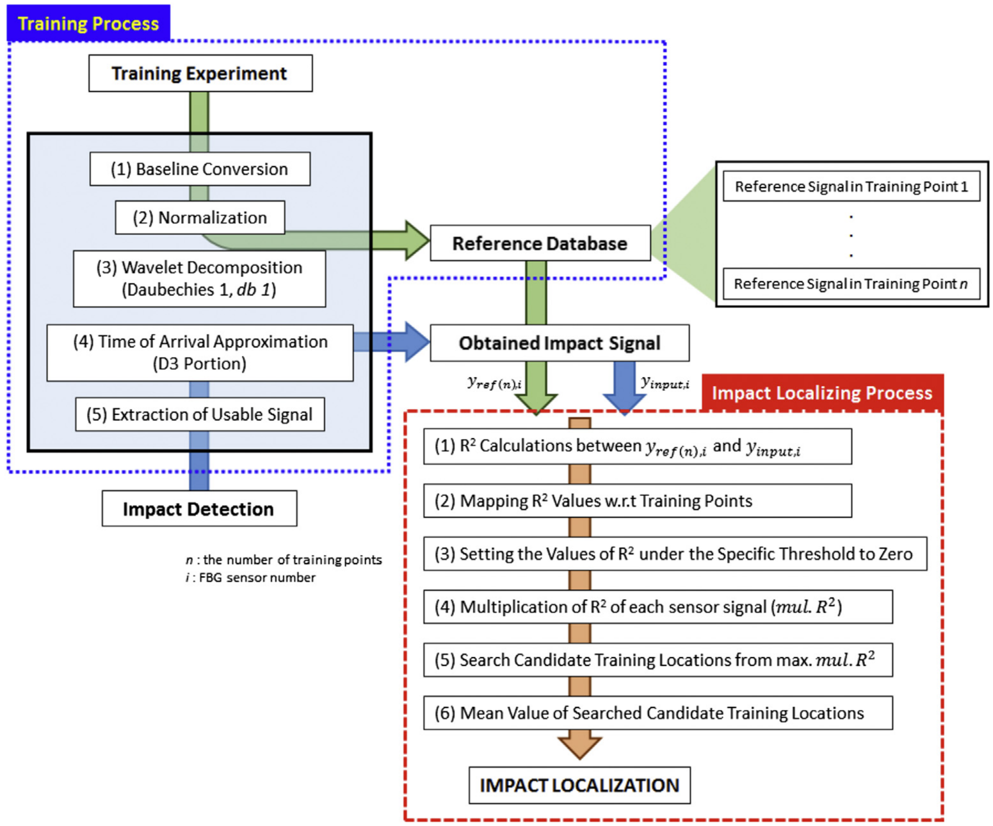

Fig. 1. Flow chart for the impact localization algorithm.

wave speed. To extract time differences of impact signals, different kinds of wavelets such as Shannon, Morlet and Gabor were employed in these studies. While many researchers [23–26] adopted the neural network algorithm for localizing impact events, there have some vulnerabilities due to difficult measurement of stable inputs and convergence problems. The time reversal method also has been considerably investigated for impact and damage assessments. Though a priori information about impact-induced waves and structural properties are not required for some of these studies [29–32], they need much of sensors and high quality signals to reduce measurement errors. Because the increase of required sensors cause to raise the complexities in the sensor installation and signal processing, the time reversal method has a limited capability to monitor the impact events for large structures in real time. The database reference method [33–35] could provide the acceptable localization results with a relatively small number of sensors. It is possible to use low quality impact signals obtained from fiber Bragg grating (FBG) sensors with a low sampling frequency and signal-to-noise (SNR) ratios. Jang et al. [33] performed the reference signal based impact localizations on a composite stiffened panel under external dynamic loading condition with an FBG sensor array. Kim et al. [34] and Shrestha et al. [35] also utilized the impact signals acquired from FBG sensors to implement impact identifications using a normalized cross-correlation and root mean squares (RMS)/correlation method respectively. FBGs are promising sensor systems for on-board global health monitoring of the operational structures because they have great properties such as simple multiplexing capability, immunity to electro-magnetic interference (EMI), no need to bulky lead wires and so on. Thus, these reference data based methods are advantageous to cover a larger application area than other methodologies. However, many reference signals from the dense training points are essential prerequisites for applying the existing database reference methods. Thus, much of time has to be spent on conducting the training procedure. Also, a number of impact experiments to obtain the reference signals could be one of the factors to induce potential damages in the target structures.

Therefore, in this paper, the impact localization scheme for reducing the number of training points is proposed to enhance the applicability of database reference methods. Basically, the proposed method identifies the impact locations by comparing the coefficient of determination (R^2) between a pre-obtained reference database and the measured impact signals. Using this method, the effect of the number of training points was studied by estimating the impact locations from the dense and coarse training cases. To reduce the localization errors within the allowable error bounds dependant to the distance between training points, the averaging signals from the adjacent reference signals were added to the database as the imaginary reference signals. As a result, we could successfully estimate the impact locations with an acceptable error value from a relatively small number of training points.

2. Impact localization algorithm

2.1. Extraction of usable signal

The impact localization algorithm proposed in this study is composed of two main processes, the training and impact localizing