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A Method for Compensation of Changing Environmental and Operational Conditions for Structural Health Monitoring Using Guided Waves

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Summary

Structural health monitoring (SHM) systems using guided waves permit the detection of structural damage via a network of permanently attached or embedded sensors. The benefits of such systems in terms of the reduction of maintenance and operation costs across many industries are now widely recognised. To identify the presence of damage, the amplitude of residual wave signals remaining after the subtraction of the reference data is often utilised in damage diagnostics. However, even in the absence of structural damage, these residual signals are usually not non-zero because of changing environmental or operational conditions (EOCs). Therefore, some form of compensation for variable EOCs is absolutely essential for guided wave based SHM methods reliant on baseline subtraction, to work accurately in real-world applications.

Many studies have demonstrated that the effect of changing EOCs can mask damage to such a degree that a critical defect might not be detected. Several effective strategies, based on signal processing, have been developed in recent years, specifically in order to compensate for ambient temperature variations. Nevertheless, many other factors and conditions, such as a progressive failure of the actuator and the adhesive bonding layer, changing humidity and boundary conditions or degradation of material properties, cannot be identified or compensated for with the existing strategies and techniques.

This research describes a conceptually new method, which is capable of reconstructing the baseline time traces corresponding to the current state of the structure and EOCs. Thus, there is no need for any other compensation for EOCs when using this method for damage diagnosis. The method is based on 3D surface measurements of the velocity field near the actuator, using laser vibrometry in conjunction with high-fidelity finite element simulations of guided wave propagations in the defect-free structures. To demonstrate the feasibility and efficiency of the proposed method, the thesis provides several examples of the reconstruction of named baseline time traces and damage detection in isotropic and composite structural components.

It is recognised that the utilisation of 3D laser measurement systems and transient FE simulations can significantly increase the cost of the damage detection if this method is to be employed in practice. However, it is believed that with the advances in computer and laser technologies the cost-efficiency can be significantly improved and, in the future, the method will be applied in a wide range of engineering applications. It should be highlighted that for the current thesis the concept and idea have been verified through comprehensive numerical and experimental studies and this is a fundamental step in the development of this innovative method. As a result, this thesis is largely focused on the feasibility, quantifiable proof of the conceptualisations underpinning the thesis and demonstrations of the potential of this new development in engineering applications.

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Declaration by Author

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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Pouria Aryan *Date*

Nomenclature

Symbol	***Definition***
Latin Alphabet	
A	Amplitude of sinusoidal tone burst
A_0	Fundamental anti-symmetric mode of Lamb waves
C_g	Group velocity
C_p	Phase velocity
C_L	Longitudinal bulk wave velocity
C_T	Transverse bulk wave velocity
d	Distance from actuator
E	Young’s modulus
f	Frequency
h	Half of plate thickness
G	Shear modulus
k	Wavenumber
k_p	The coefficient relating changes Phase velocity
L	Length of scanning area
N	Number of cycles
P	Remote point
S_0	Fundamental symmetric mode of Lamb waves
t	Time
U	Displacement
V	Velocity
$w(t)$	Hanning window function
Greek Alphabet	
α	Coefficient of thermal expansion

λ	Wavelength
v	Passion’s ratio
ρ	Density
μ	Shear modulus of elasticity
ω	Angular frequency
φ	Displacement potential
ψ	Displacement potential

Acronyms

1D	One-dimensional
2D	Two-dimensional
3D	Three-dimensional
AE	Acoustic emission
BSS	Baseline signal stretch
CFRP	Carbon fiber reinforced polymer
DDT	Damage detection technique
DOF	Degree of freedom
EC	Eddy current
EOC	Environmental and operational condition
FBG	Fiber Bragg Grating
FE	Finite element
GW	Guided wave
NDT	Non-destructive testing
OBS	Optimal baseline selection
PZT	Lead Zirconate Titanate Transducer
RMS	Root mean square
SHM	Structural health monitoring
SLV	Scanning laser vibrometer
TOF	Time of flight

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