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Abstract

A Low-Cost Solution and Continuous Wavelet Transform Analysis for Structural Health Monitoring †

Bruno Andò [1,*], Danilo Greco [1] and Giacomo Navarra [2]

[1] Department of Electrical Electronic and Computer Engineering (DIEEI), University of Catania, 95123 Catania, Italy; danilo.greco@phd.unict.it
[2] Department of Engineering and Architecture, Kore University of Enna, 94100 Enna, Italy; giacomo.navarra@unikore.it
* Correspondence: bruno.ando@unict.it
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Abstract: In this paper, a low-cost solution for Structural Health Monitoring is proposed, exploiting a dedicated embedded sensing system. Signals provided by the sensor node have been processed by Continuous Wavelet Transform. The node behavior to seismic-like solicitations and has been assessed in the case of frequency sweeps. The results demonstrate the system's suitability for use in Early Warning frameworks.

Keywords: structural health monitoring; embedded systems; continuous wavelet transform

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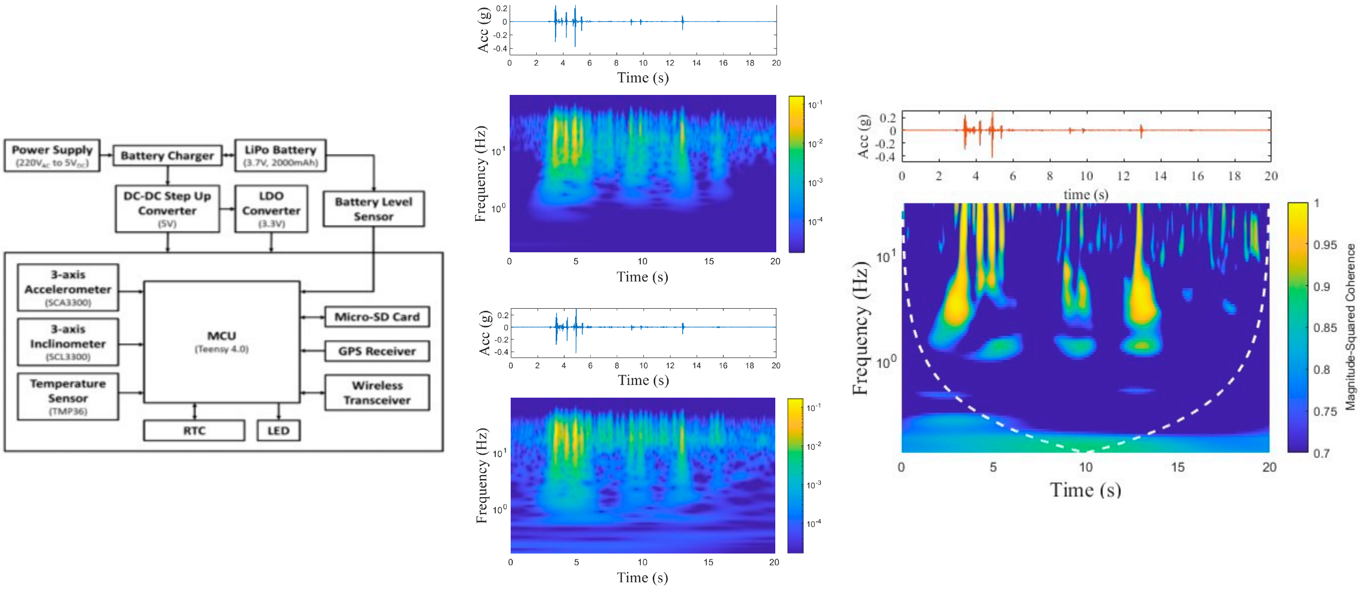
1. Introduction

Traditional Structural Health Monitoring (SHM) approaches employ periodic inspection, performed by the mean of high-cost and very accurate instrumentation, which is neither real-time nor spatially dense [1], thus leading to a lack of information. On the other hand, continuous monitoring, implemented by a permanent network of sensors, allows for the continuous and conveniently distributed monitoring of health-related quantities and the consequent tracking of the short- and long-term modification of the structure. The activity presented through this work aims to develop a sensing architecture compliant with use in an Early Warning System for SHM. The main outcomes of the solution proposed through this work, also in terms of novelties with respect to previous works [2,3], are mainly related to implemented signal processing, which uses a Continuous Wavelet Transform (CWT) to properly investigate the time-frequency content of recorded events. The latter, with respect to Discrete Wavelet Transform (DWT), offers a more accurate frequency sampling, thus providing a more reliable analysis of the signal content. This is strategic for the analysis of transient dynamics. Moreover, cross-correlation-based re-alignment and the coherence function have been used to assess the system performances against reference instrumentation.

2. The Developed Approach and Experimental Results

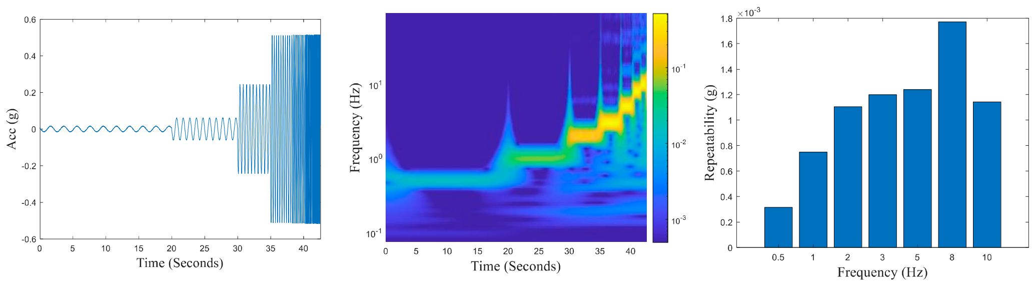
The embedded sensing node, schematized in Figure 1a, mainly consists of the SCL3300-D01-PCB inclinometer and SCA3300-D01-PCB accelerometer (showing a linearity error of 1 mg), the Teensy 4.0 module equipped with a Real-Time Clock, a GPS module, and a Bluetooth transceiver. The node sampling frequency is 200 Hz. Since seismic solicitations and the related responses of monitored structures can convey interesting content at a different timescale, a CWT-based approach has been used to analyze the time-frequency content of recorded signals. The adopted CWT uses the analytic Morse wavelet with the symmetry parameter equal to 3, the time-bandwidth product equal to 60, and 10 voices per octave. Auto-triggering of the scales is also used on the basis of the energy spread of the wavelet both in terms of frequency and time. L1 normalization is used, allowing for the better preservation of energy with respect to other forms of normalization. The correlation between signals recorded by the sensor node and the reference sensor has been elaborated on by the wavelet coherence operator.



(**a**) (**b**) (**c**)

Figure 1. (**a**) The node schematization; (**b**) recorded signals by the reference accelerometer (top) and the embedded node (bottom); (**c**) wavelet coherence.

The sensor node features in detecting vibrational stimuli have been accomplished by using a dedicated experimental set-up, consisting of an electrodynamic shaker and a reference Titan accelerometer. Seismic-like signals with a dominant frequency bandwidth around 10 Hz have been used to drive the shaker. An example of recorded signals is given in Figure 1b. The wavelet coherence analysis between the two signals, shown in Figure 1c, allows for confirming the suitability of the sensor node behavior, which is coherent with the dynamics recorded by the reference accelerometer. The frequency response of the node has also been assessed. An example of a frequency sweep recorded by one of the accelerometer axes of the node is given in Figure 2a, while Figure 2b shows the corresponding CWT. The results obtained by the repeatability test are reported in Figure 2c. An average system repeatability of 1.0 mg in the acceleration measurement has been estimated, by considering the 3σ estimation among a set of repeated readings, which is compliant with the nominal specifications of the adopted sensors and in line with the requirements of the envisaged application contexts.



(**a**) (**b**) (**c**)

Figure 2. (**a**) Frequency sweep; (**b**) CWT of (**a**); (**c**) repeatability of the test results.

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