HORIZON 2020

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH

TRUSS
Training in Reducing Uncertainty in Structural Safety

ESREL 2017

Evaluation of the Hilbert Huang Transformation of Transient Signals for Bridge Condition Assessment

John Moughty & Prof. Joan Ramon Casas

Technical University of Catalonia (BarcelonaTech)

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Outline

Research motivation and overview

Test data (Steel Truss Bridge)

Empirical Mode Decomposition

Application of Hilbert-Haung Transform (HHT)

Conclusions

Research Motivation

- Fourier Transforms (FTs) are commonly employed to assess the structural condition of bridge structures, however, FTs require the system response to be linear and strictly stationary.
- Operational bridge vibrations are not generally linear or stationary.
- Non-stationarity of response signals may increase with damage.

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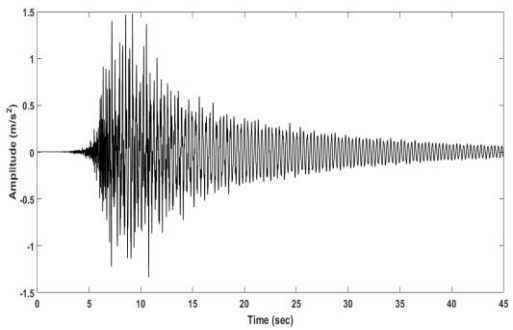
Table 1. Signal Transformations

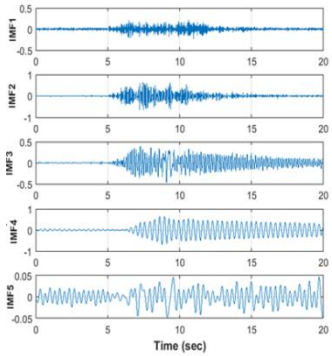
	Fourier	**Wavelet**	**Hilbert-Haung Transform**
Frequency Calc.	Global Convolution	Global Convolution	Local Differentiation
Presentation	Energy & Frequency	Energy, Time & Frequency	Energy, Time & Frequency
Non-Linear	No	No	Yes
Non-Stationary	No	Yes	Yes

Hilbert Huang Transform: Process Overview



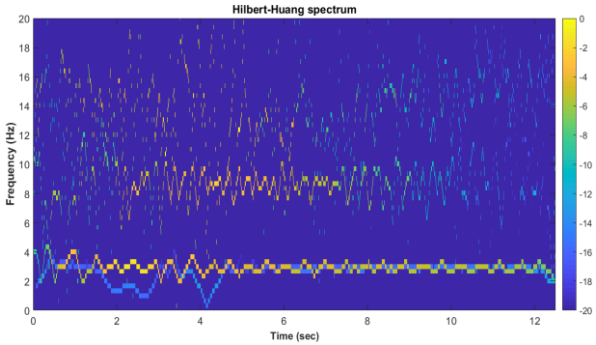
Signal In

EMD



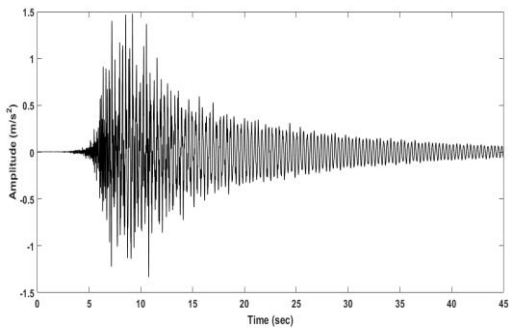
IMFs

HHT



Hilbert-Huang Spectrum

Hilbert Huang Transform: Process Overview



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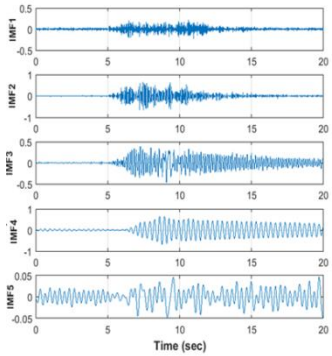

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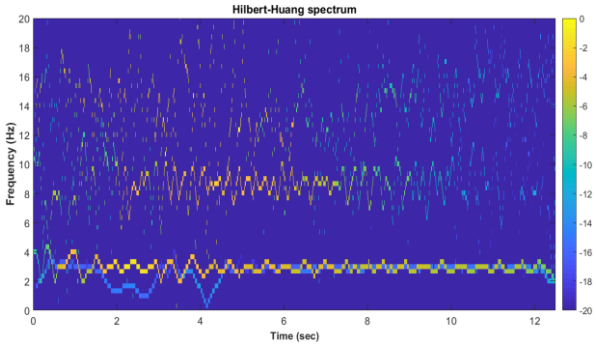
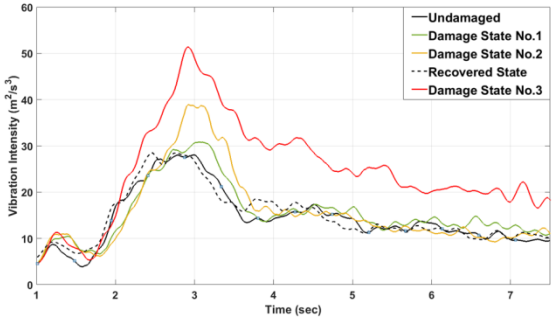
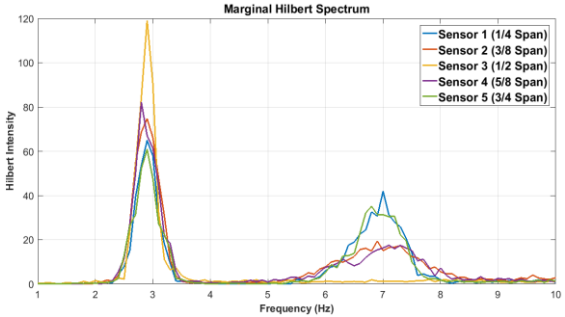


Hilbert-Huang Spectrum

MORE

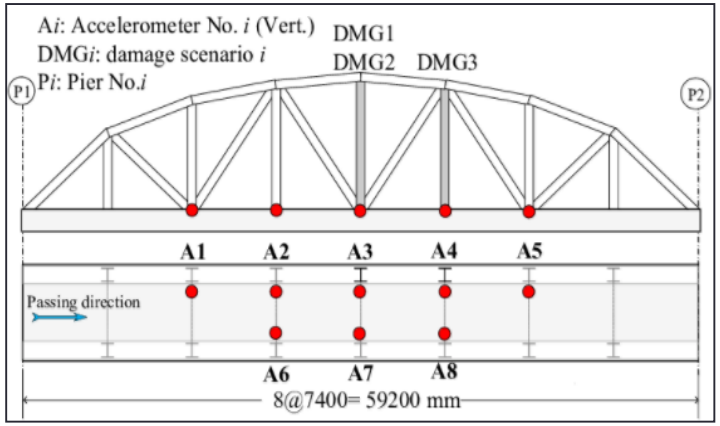


Instantaneous Energy

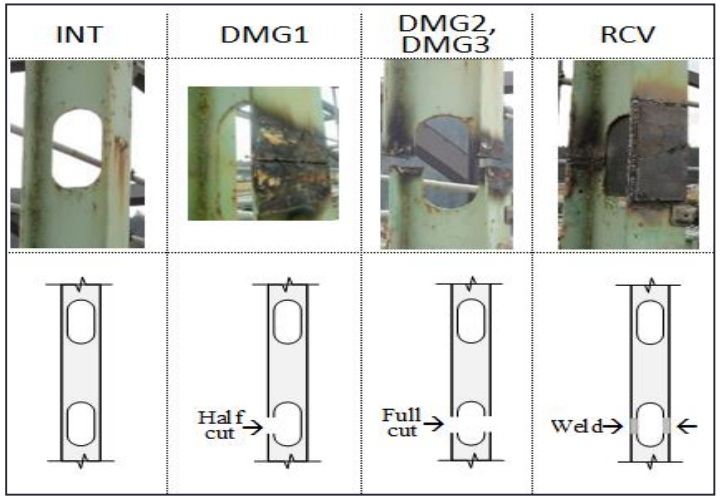


Marginal Hilbert Spectrum

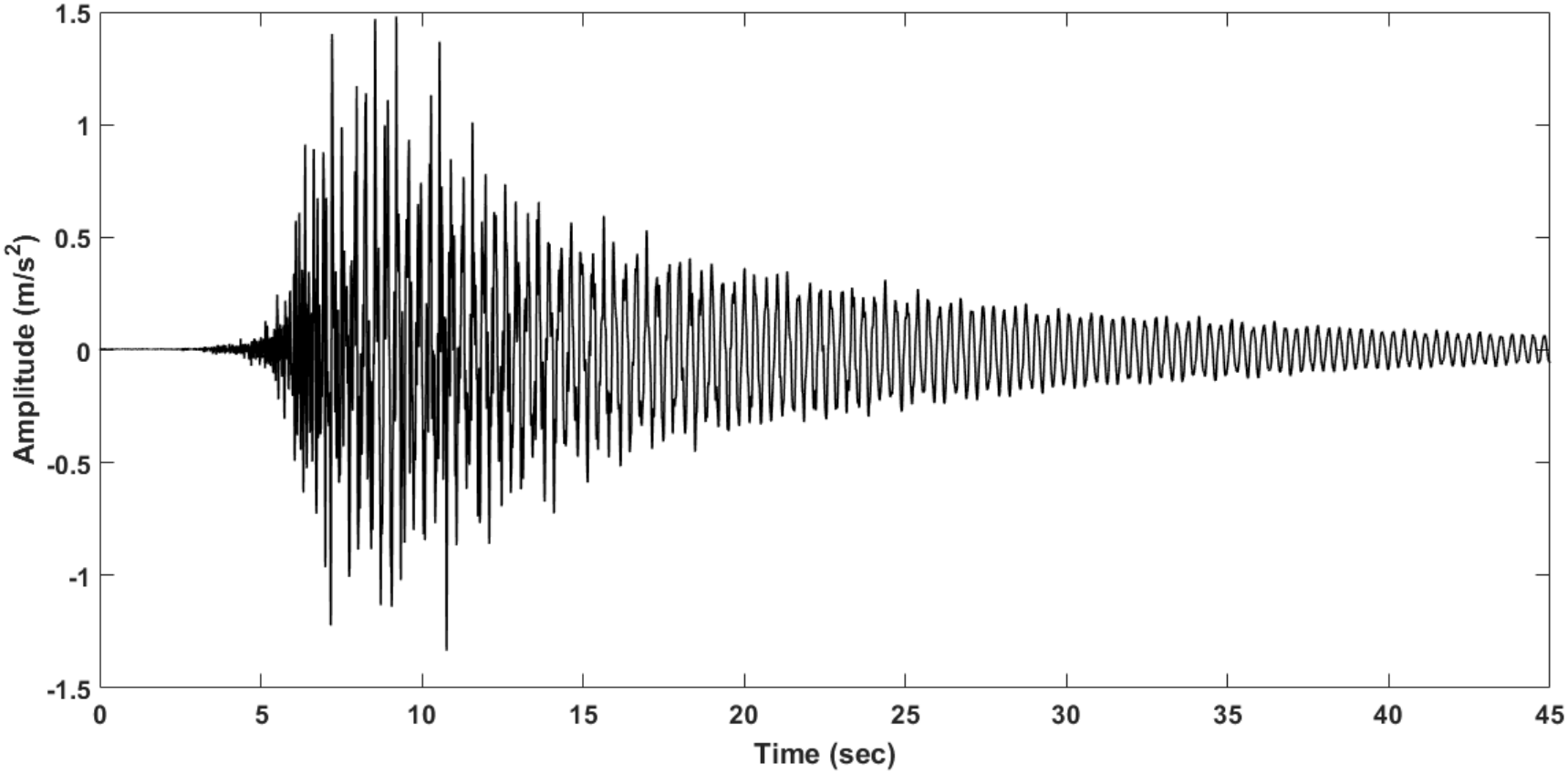
Steel Truss Bridge: Progressive Damage Test



- Steel truss bridge subjected to 4 damage scenarios to central vertical members
- A 21kN double-axle vehicle with a velocity of 40km/hr was used for structural excitation
- Vertical acceleration response of vehicle passage was recorded from 8 locations



Recorded Structural Response



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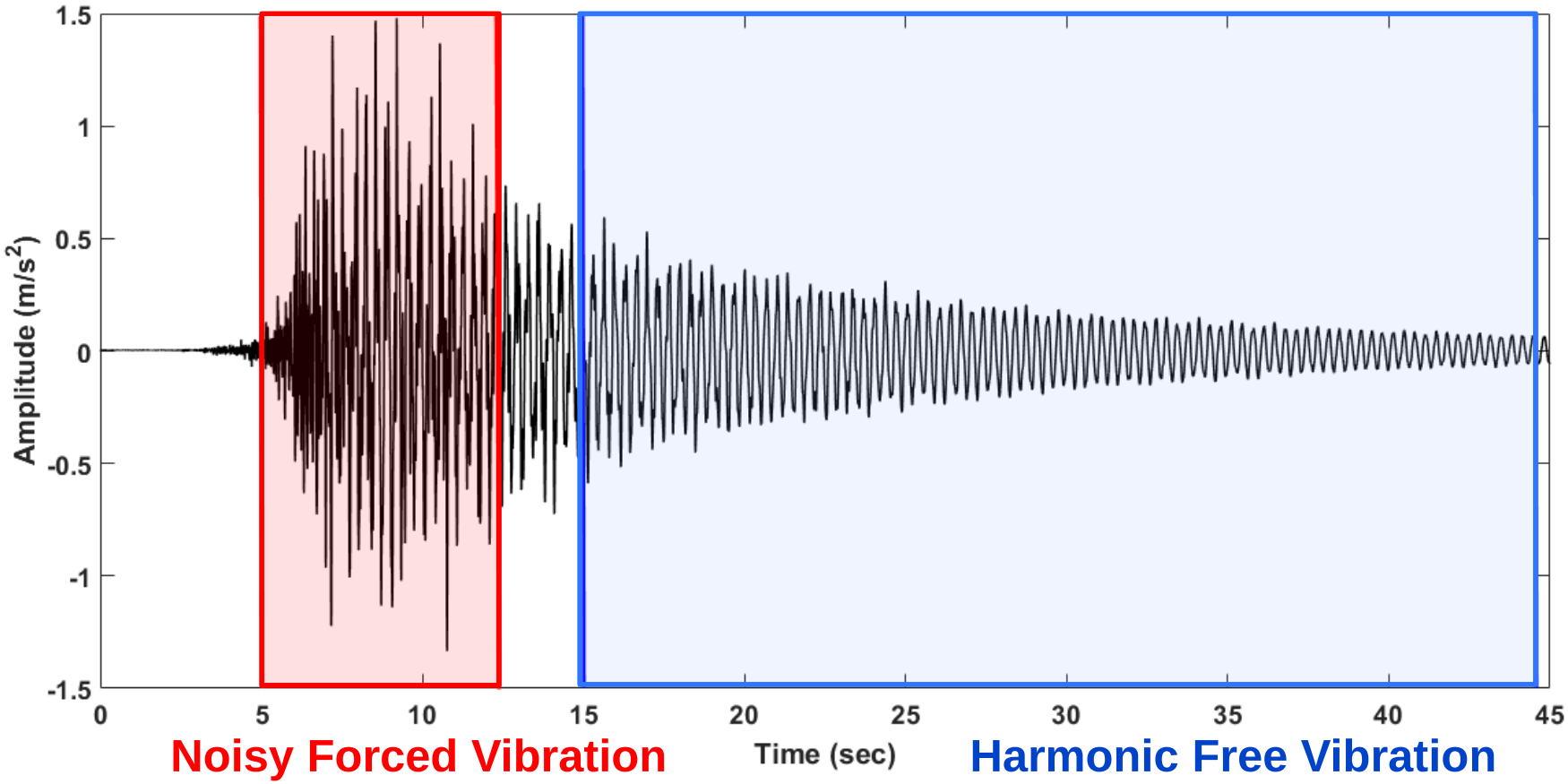
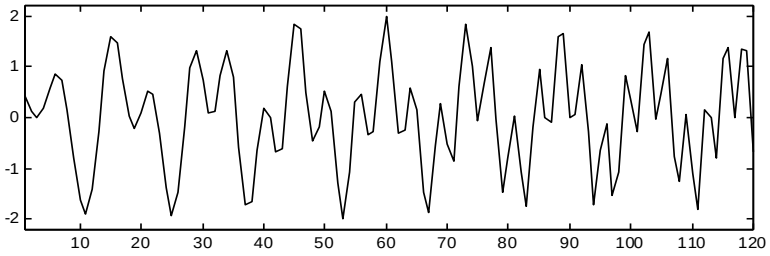
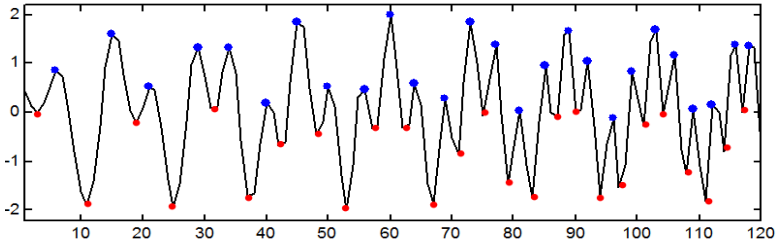


Empirical Mode Decomposition



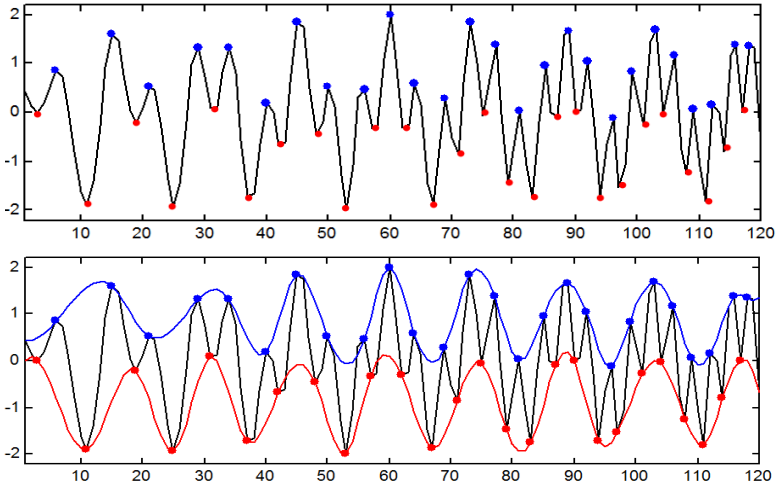
Empirical Mode Decomposition

1. Identify all extrema in the signal $x(t)$



Empirical Mode Decomposition

1. Identify all extrema in the signal $x(t)$
2. Interpolate with cubic spline function between minima points & maxima points to form an envelope $e_{min}(t)$ & $e_{max}(t)$



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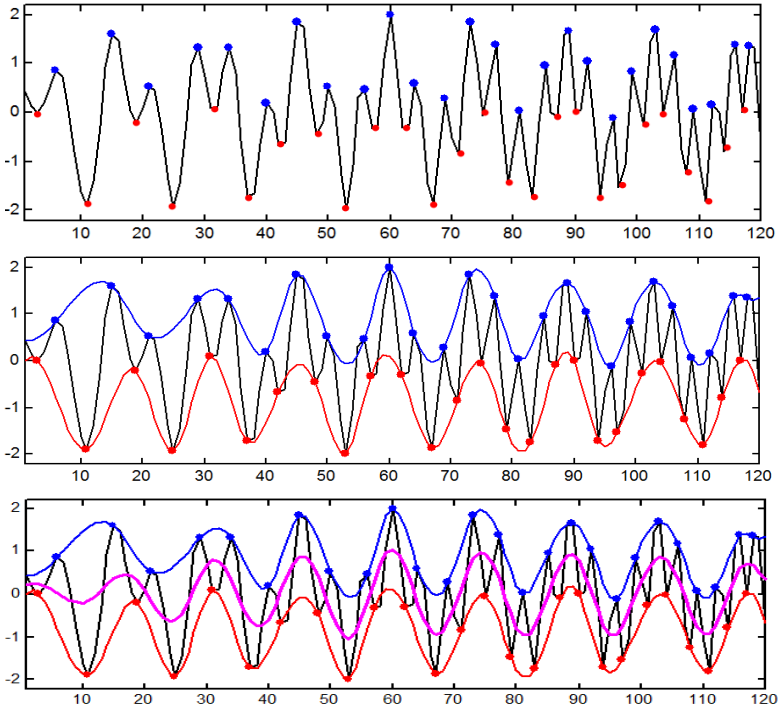

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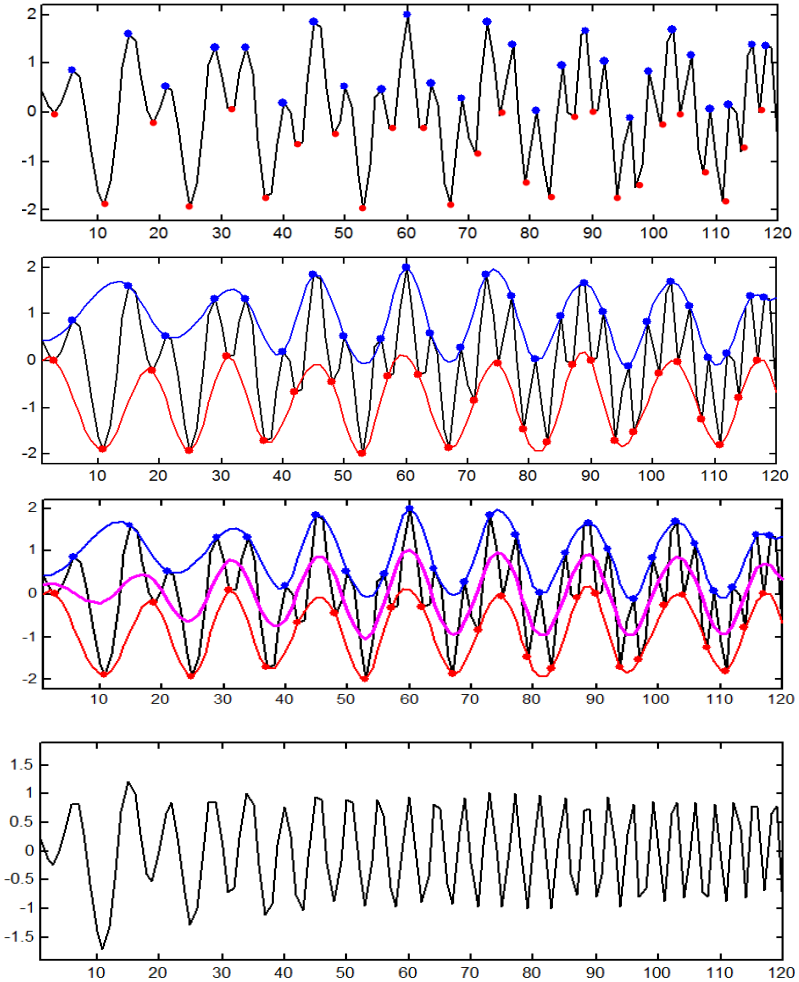

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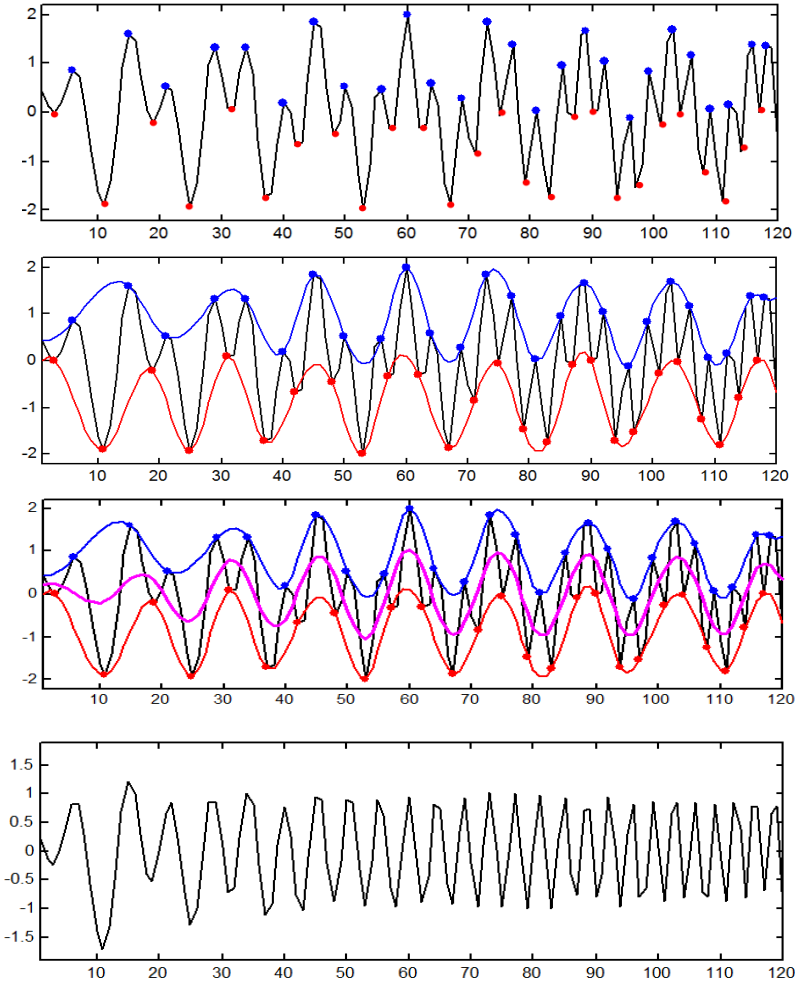
5. Check if $d(t)'s$ extrema & zero crossings differ by a maximum of 1, and if $d(t)$ satisfies the stopping criterion based on consecutive standard deviation values.



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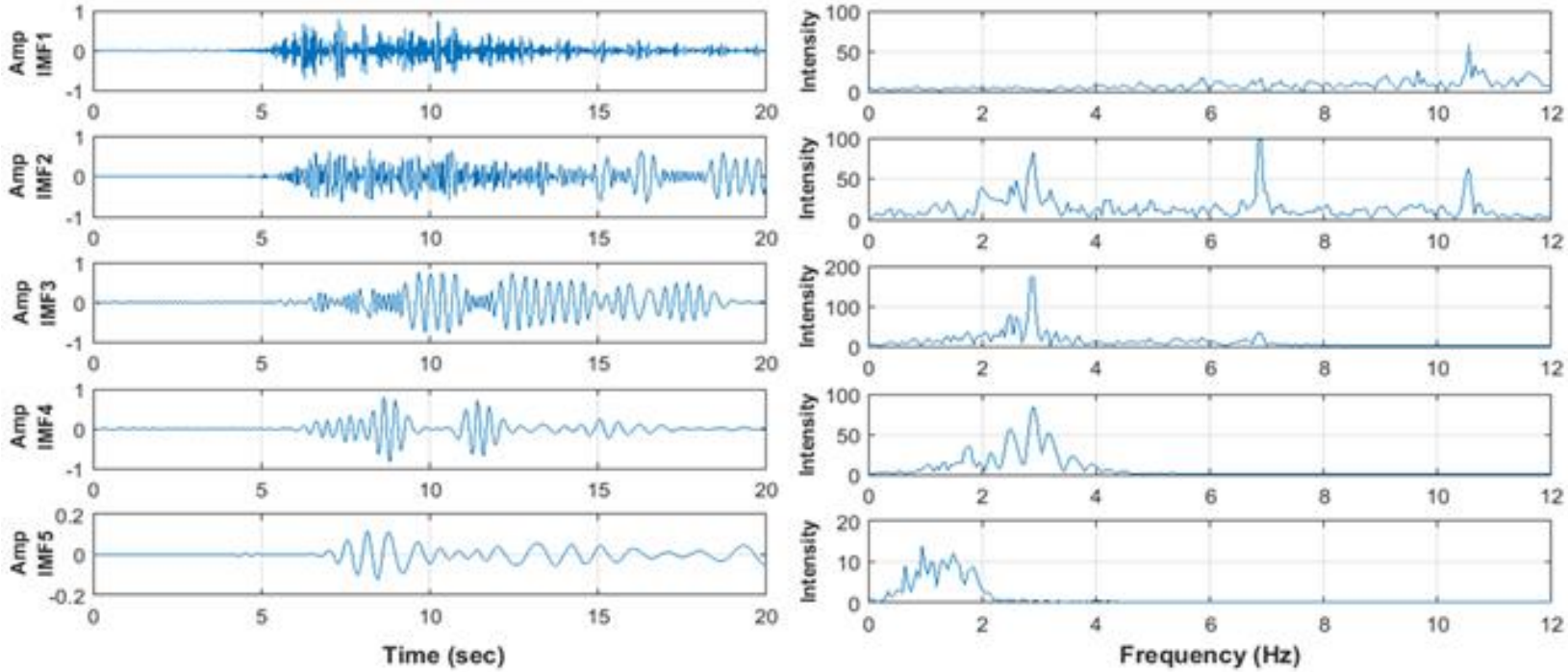


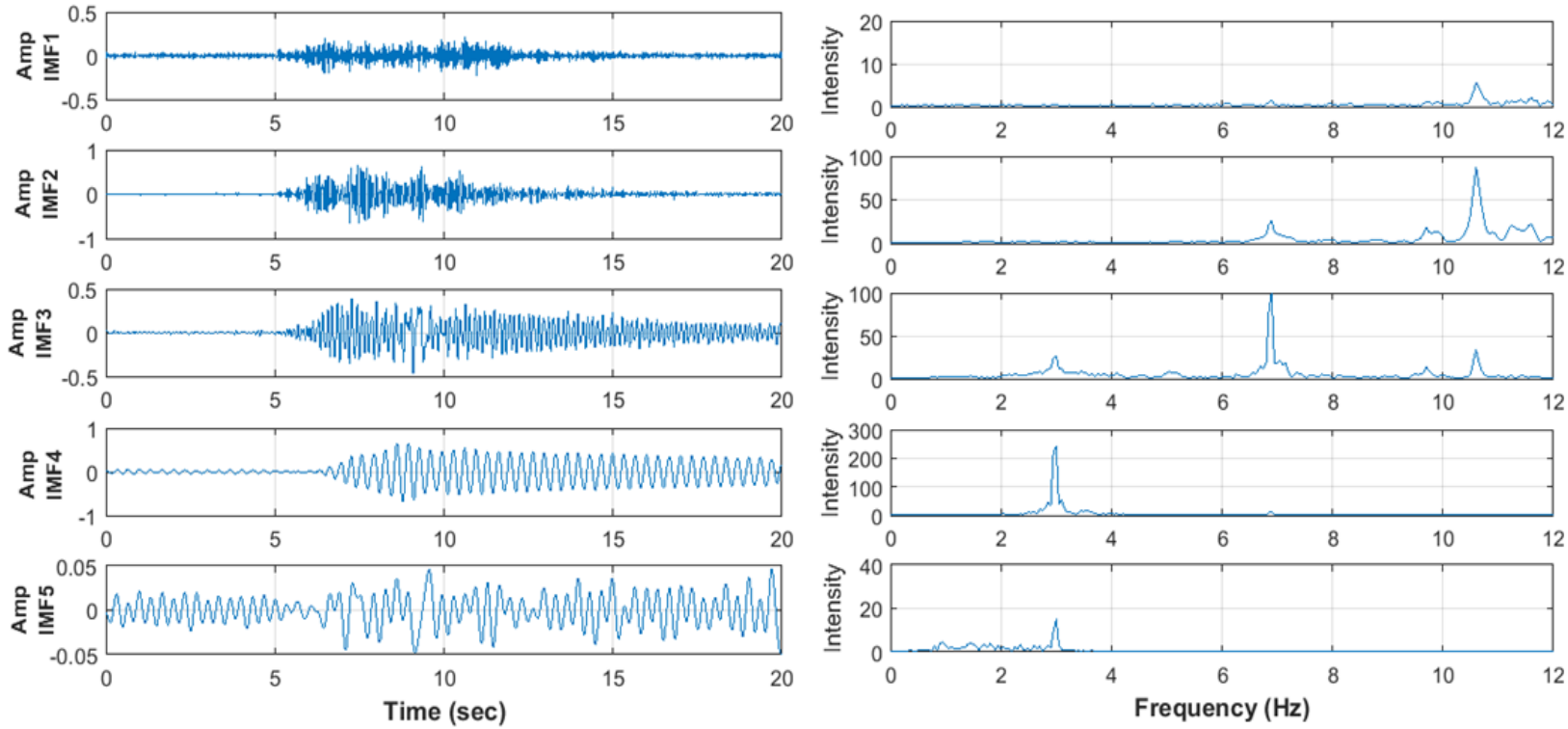
Decomposed IMFs **FFTs of IMFs**

EMD: Advancements

Ensemble Empirical Mode Decomposition (EEMD)

- Gaussian white noise with the same variance as the noise within the original signal is added for multiple realisations
- Added noise alters the signal slightly while retaining its physical meaningful information
- Mode mixing is reduced considerably

Ensemble Empirical Mode Decomposition



Decomposed IMFs **FFTs of IMFs**

Hilbert Transform

Hilbert transform $H[c_i(t)]$ can be applied to the IMFs $c_i(t)$ to obtain an analytic signal z(t) that contains instantaneous amplitude $a_i(t)$ and phase $\theta_i(t)$, which can be differentiated to obtain instantaneous frequency.

$$H[c_i(t)] = \frac{1}{\pi}\int_{-\propto}^{\propto} \frac{c_i(\tau)}{t-\tau} d\tau$$

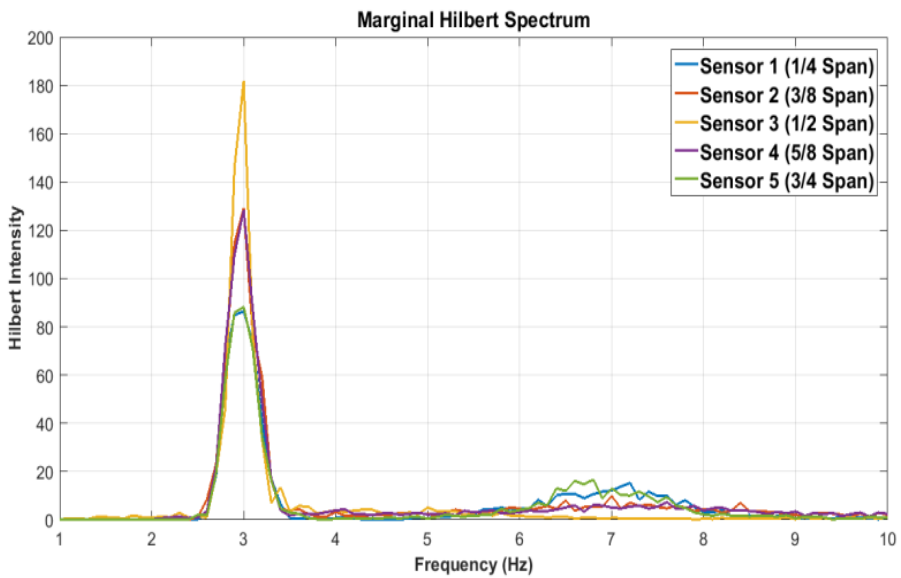
$$z(t) = c_i(t) + jH[c_i(t)] = a_i(t)e^{j\theta_i(t)}$$

$$a_i(t) = \sqrt{c_i{}^2(t) + H^2[c_i(t)]}$$

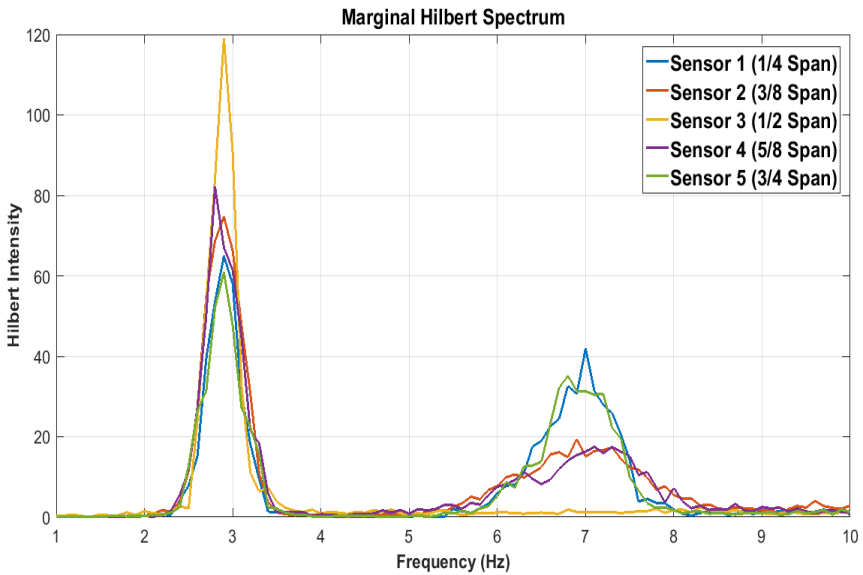
$$\theta_i(t) = arctan\left(\frac{H[c_i(t)]}{c_i(t)}\right)$$

$$\omega_i(t) = \frac{d\theta_i(t)}{dt}$$

HHT Results: Marginal Hilbert Spectrum



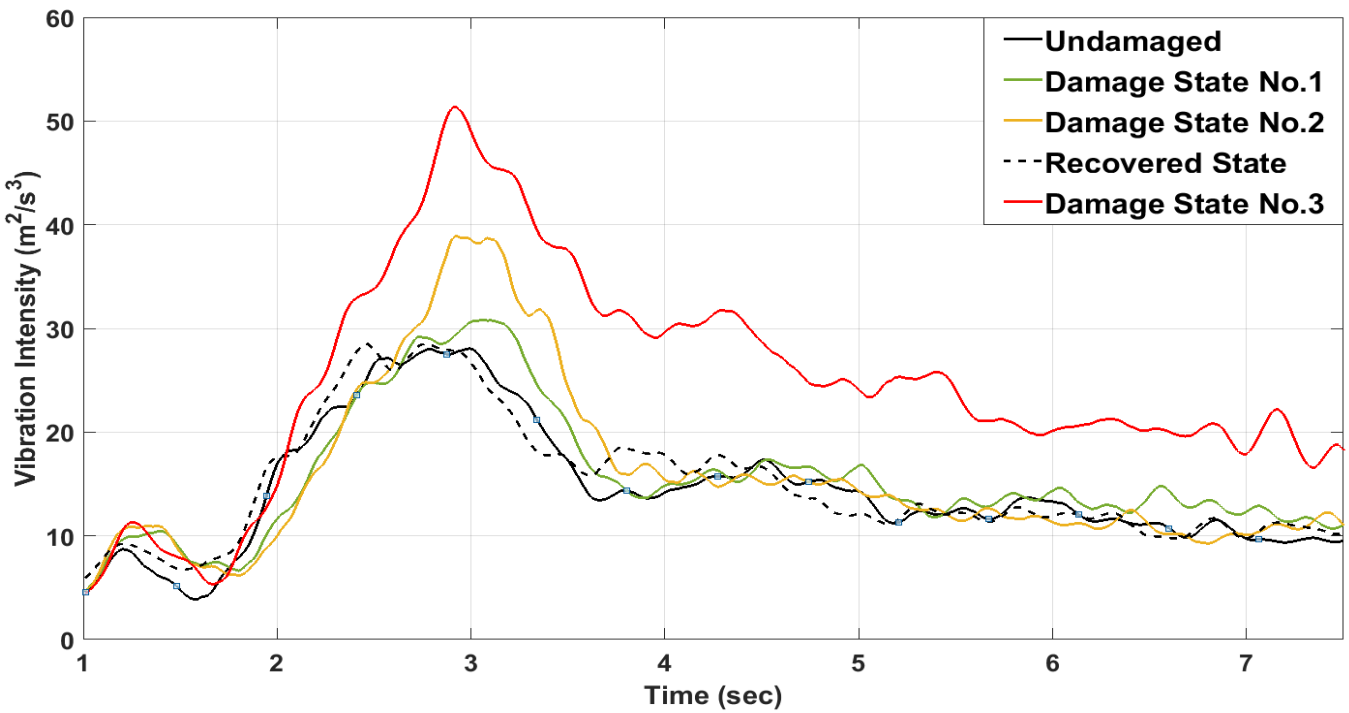
All Sensors Undamaged



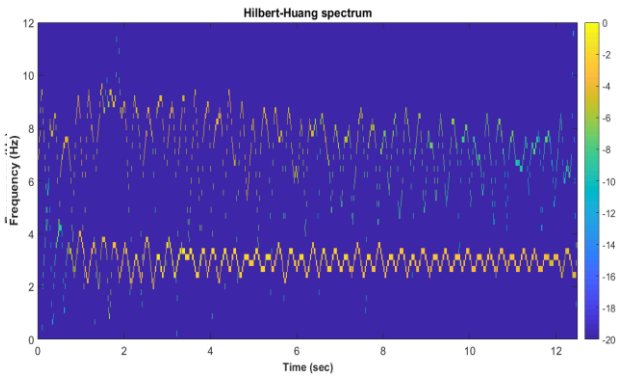
All Sensors Damaged

HHT Results: Instantaneous Vibration Intensity

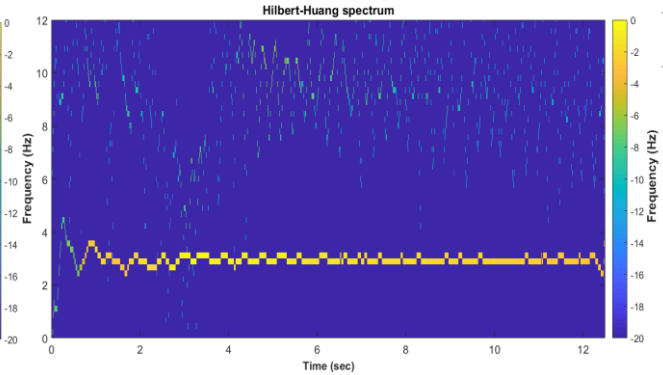
$$(Vibration\ Intensity = \frac{Energy}{freq} = a_0{}^2/f)$$



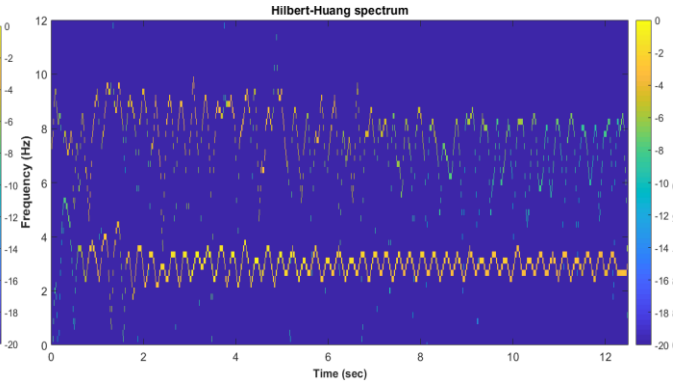
HHT Spectrum Results



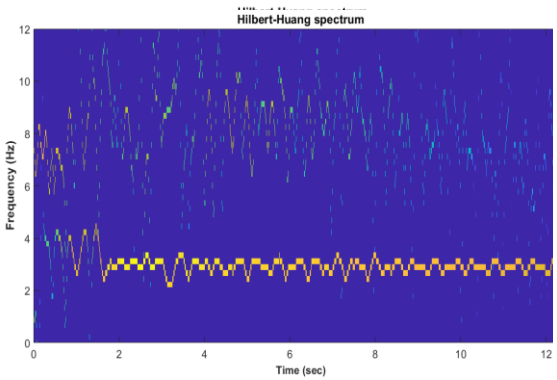
Sensor 2 Undamaged



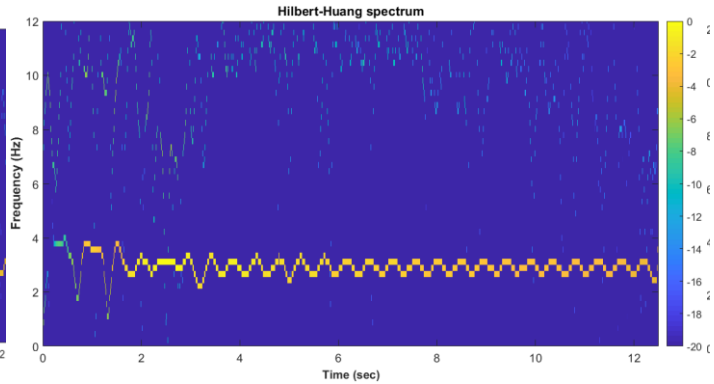
Sensor 3 Undamaged



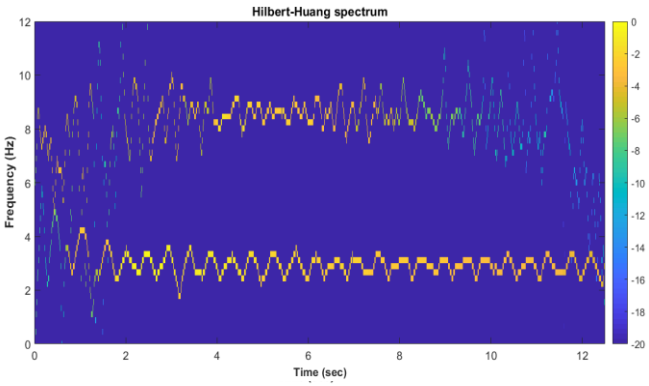
Sensor 4 Undamaged



Sensor 2 Damage 3



Sensor 3 Damage 3



Sensor 4 Damage 3

Conclusions

- EEMD is an adaptive method decomposing a non-linear non-stationary signal with physical meaningful results (no mode-mixing).
- Instantaneous Vibration Intensity may attain considerable damage sensitivity
- HHT Spectrums demonstrated the ability to locate structural changes in a symmetrical structure
- Additional work is required for multivariate EMD to enhance HHT Spectrum results

THANK YOU FOR YOUR ATTENTION

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