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

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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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- Operational bridge vibrations are not generally linear or stationary.
- Non-stationarity of response signals may increase with damage.

<table>
<thead>
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<th>Fourier</th>
<th>Wavelet</th>
<th>Hilbert-Haung Transform</th>
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<tr>
<td><strong>Frequency Calc.</strong></td>
<td>Global</td>
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<td>Local Differentiation</td>
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<td><strong>Presentation</strong></td>
<td>Energy &amp; Frequency</td>
<td>Energy, Time &amp; Frequency</td>
<td>Energy, Time &amp; Frequency</td>
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<tr>
<td><strong>Non-Linear</strong></td>
<td>No</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td><strong>Non-Stationary</strong></td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
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Hilbert Huang Transform: Process Overview

Signal In → EMD → IMFs → HHT → Hilbert-Huang Spectrum
Hilbert Huang Transform: Process Overview

- **Signal In**
- **EMD**
- **IMFs**
- **HHT**
- **Hilbert-Huang Spectrum**
- **Instantaneous Energy**
- **Marginal Hilbert Spectrum**

MORE +
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
Recorded Structural Response

Noisy Forced Vibration

Harmonic Free Vibration
Empirical Mode Decomposition
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4. Extract the detail $d(t) = x(t) - m(t)$

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.
Empirical Mode Decomposition

Decomposed IMFs

FFT 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.

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

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

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

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

$$\omega_i(t) = \frac{d\theta_i(t)}{dt}$$
HHT Results: Marginal Hilbert Spectrum

All Sensors Undamaged

All Sensors Damaged
HHT Results: Instantaneous Vibration Intensity

\[(Vibration\; Intensity = \frac{\text{Energy}}{\text{freq}} = a_0^2/f)\]
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