USE OF WAVELETS IN THE ANALYSES OF BIODYNAMIC RESPONSES

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INTRODUCTION

Biodynamic responses are usually transient, strongly localized in the time domain, and contaminated with noise, so that conventional statistical analysis, correlation analysis, or spectral analysis used for stationary signals may be neither appropriate nor efficient for the analyses of them. Wavelets, localized in both frequency and time domain, match the major characteristics of biodynamic responses. The use of wavelets in the analyses of biodynamic responses for various applications was investigated by the authors and is briefly described below.

WAVELET/WAVELET PACKET DECOMPOSITIONS

A biodynamic response or signal $S(t)$ can be decomposed on a wavelet basis [1]:

$$S = A_J + \sum_{j \le J} D_j \,, \qquad (1)$$

where the approximation A_J retains the lower frequency components of the original signal, and the details D_j contain high frequency components and often display vibrations and noises. In a wavelet packet basis, the decomposition of $S(t)$ at level J can be expressed as [2]

$$S(t) = \sum_{n=0}^{2^J-1} \sum_k q_{Jnk} w_{Jn}(t-k) \,, \qquad (2)$$

where $w_{Jn}(t)$ are wavelet packet atoms; q_{Jnk} are wavelet packet coefficients; n is the frequency index, and k is the position index. The wavelet transform allows for a view of biodynamic response in a time-frequency plane, and thus provides the information regarding when events take place.

CORRELATION ANALYSIS

Decompose two signals $x(t)$ and $y(t)$ at a certain level using wavelets. The approximations $x_a^l(t)$ and $y_a^l(t)$ can be treated as deterministic signals, and the linear relationship or resemblance between them can be described by a classic correlation coefficient $\rho_a^l(\tau)$ [3]. The time shift τ is allowed to account for the phase shift between them. A quantity

$$\rho_{am}^l = \rho_a^l(\tau_m) = \max_{\tau}\{\rho_a^l(\tau)\} \,, \qquad (3)$$

can be used to evaluate the agreement in the pulse shape, whereas τ_m can be used to measure the time shift. As dyadic wavelet decomposition provides a multi-resolution analysis, the correlation analysis between the approximations at different levels describes the correlative relationship between the two original signals with different resolutions.

SIGNAL ENERGY DISTRIBUTION ANALYSIS

If a signal is decomposied on an orthogonal wavelet packet basis using Eq. (2), in terms of the signal energy [3],

$$\|S\|^2 = \sum_{n=0}^{2^j-1} \sum_k q_{jnk}^2 \,. \qquad (4)$$

The signal energy distribution can be defined in two ways:

- With respect to the frequency index n:

$$E_n = \sum_k q_{Jnk}^2 \,; \qquad (5)$$

- With respect to the time position k and the frequency index n:

$$E_{n,k} = q_{Jnk}^2 \,. \qquad (6)$$

MODEL VALIDATION

The comparison of the energy distributions of a pair of biodynamic responses from a test and from the simulation shows the agreement or discrepancy in amplitudes between them; thus it can be used for the validation of bio-computational modeling. In order to compare the pulse shape and the peak timing between the two responses, the correlative relationship between the approximations can be used. Based on energy distributions and correlation analysis, several metrics were developed that can be used for quantitative validation. The comparison can be made at different levels so that details at different scales can be taken into account.

PREDICTING HUMAN RESPONSE FROM ATD TESTS

The ATD (Anthropomorphic Test Device) response and human response are considered as the output of a black box system. Based on the decompositions of both responses on a wavelet packet basis, a mapping matrix is built after executing a procedure including de-noising, energy distribution analysis, correlation and regression analysis, and spectral coherence analysis and transfer function identification [4]. With the mapping matrix, an ATD response can be modified or reconstructed into the corresponding human response.

CONCLUSIONS

Wavelet analysis is a useful and effective tool for the analyses of biodynamic responses in various applications.

REFERENCES

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