New method for simulation earthquake records by using adapted wavelet

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ABSTRACT:

For earthquake resistant design of critical structures, a dynamic analysis, either response spectrum or time history is frequently required. Owing to the lack of recorded data and the randomness of earthquake ground motion that may be experienced by structure in the future, usually it is difficult to obtain recorded data which fit the requirements (site type, epicenteral distance, etc.) well. Therefore the artificial seismic waves are widely used in seismic designs, verification of seismic capacity and seismic assessment of structures.
With the emergence of wavelet transformation as a powerful tool of time–frequency analysis in recent years, it has become possible to account for frequency non-stationary behavior more conveniently.
The main target of this paper is to present a new method which apply advanced time-frequency analysis, best basis search algorithm, that uses wavelet packet to generate more artificial accelerogram which are compatible with target spectrum. Application of this method for some Iranian earthquakes is presented to compare actual and synthetic accelerograms to each other to demonstrate the effectiveness of model.

Key words: artificial earthquake, target spectrum, wavelet packet.

1. INTRODUCTION

The response of structures under earthquake ground motions can be calculated either using a (pseudo-acceleration) response spectrum or an acceleration time history. For design purposes, the seismic codes provide a design spectrum, i.e. a smooth response spectrum that (hopefully) takes into account every possible earthquake. The major drawback of the response spectrum analysis in seismic design of structures lies in its inability to provide temporal information of the structural responses. Such information is sometimes necessary in achieving a satisfactory design.
Dynamic behaviors of inelastic structures during an earthquake are very complex non-stationary processes which are expected by random characteristics of earthquake motions not only in the frequency domain but also in the time domain. Since earthquake is a random base phenomenon, it is impossible to detect clearly a possible future earthquake in specified location. The most important point is that the used records should be similar to the previous record of the specified location in shape and some other important parameters. These parameters such as PGA, duration, and frequency content are used to generate an artificial earthquake.
Except for those regions of the world where recorded accelerograms are available, in the current engineering practice artificial earthquakes are still preferred for dynamic analysis despite their shortcomings. To provide input excitations to structural models for sites with no strong ground motion data, it is necessary to generate artificial accelerograms.
Iyama and Kuwamura (1999), Mukherjee and Gupta (2002), Zhou and Adeli (2003), Rajasekaran et al. (2006), and Ghodrati Amiri et al. (2006) developed the wavelet analysis for generating earthquake accelerograms. Ghodrati Amiri et al. (2006) purposed to generate many artificial records compatible with the same spectrum by wavelet theory.
In this paper, wavelet packet transform, which can express time signal by combination of time shifted by similar wavelets with different time spans, has been used to proposed the method to generate the artificial ground motion with non-stationary process by wavelet packet coefficients from multi-regression analysis.

2. WAVELET ANALYSIS

Most interesting signals contain numerous non-stationary or transitory characteristics: drift, trends, abrupt changes, and beginnings and ends of events. These characteristics are often the most important part of the signal, and Fourier analysis is not suited to detect them

In an effort to correct this deficiency, Dennis Gabor (1946) adapted the Fourier transform to analyze only a small section of the signal at a time. A technique called windowing the signal.

While the STFT compromise between time and frequency information can be useful, the drawback is that once you choose a particular size for the time window, that window is the same for all frequencies.

But many signals require a more flexible approach; one where the window size can be varied to determine more accurately either time or frequency.

Wavelet analysis represents the next logical step: a windowing technique with variable-sized regions. Wavelet analysis allows the use of long time intervals where more precise low-frequency information is needed, and shorter regions where high-frequency information is needed.

In the past few years, significant effort has been devoted to wavelets and time-frequency analysis.

With the emergence of wavelet transformation as a powerful tool of time–frequency analysis in recent years, it has become possible to account for frequency non-stationary feature more conveniently.

Wavelet analysis is capable of revealing aspects of data that other signal analysis techniques miss.

Wavelet analysis consists of decomposing a signal into a hierarchical set of approximations and details. The levels in the hierarchy often correspond to those in a dyadic scale.

A plethora of wavelets has been developed to best suit several problems in science and engineering related to transient, time-variant, or non-stationary phenomena. This gives the method a great flexibility.

3. WAVELET PACKET

The wavelet packet method is a generalization of wavelet decomposition that offers a richer range of possibilities for signal analysis. In wavelet analysis, a signal is split into an approximation and a detail. The approximation is then itself split into a second-level approximation and detail, and the process is repeated.

For an n-level decomposition, there are (n+1) possible ways to decompose or encode the signal.

In wavelet packet analysis, the details as well as the approximations can be split. This yields 2n different ways to encode the signal. Figure1 shows the wavelet packet decomposition tree.

For instance, wavelet packet analysis allows the signal S to be represented as A1 + AAD3 + DAD3 + DD2. This is an example of a representation that is not possible with ordinary wavelet analysis.

In this paper, an *entropy-based criterion* is used to select the most suitable decomposition of a given signal. This means that each node of the decomposition tree and quantify the information to be gained by performing each split.

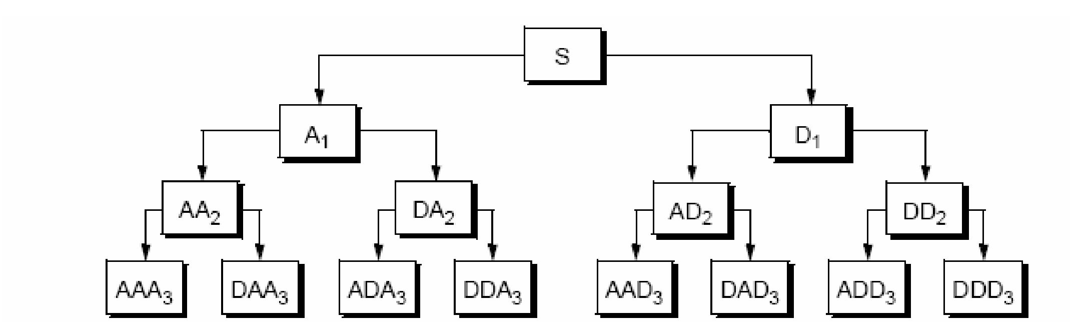

Figure 1 wavelet packet decomposition tree

This paper uses an adaptive filtering algorithm, based on work by Coifman and Wickerhauser(1994), with direct applications in optimal signal coding and data compression. Such algorithms allow the **Wavelet Packet** to include

"Best Level" and **"Best Tree"** features that optimize the decomposition both globally and with respect to each node. Wavelet packet atoms are waveforms indexed by three naturally interpreted parameters: position, scale (as in wavelet decomposition), and frequency.
In the orthogonal wavelet decomposition procedure, the generic step splits the approximation coefficients into two parts. After splitting a vector of approximation coefficients and a vector of detail coefficients, both at a coarser scale are obtained. The information lost between two successive approximations is captured in the detail coefficients. Then next step consists of splitting the new approximation coefficient vector; successive details are never re-analyzed.
In the corresponding wavelet packet situation, each detail coefficient vector is also decomposed into two parts using the same approach as in approximation vector splitting. This offers the richest analysis.
In wavelet packet analysis, the details as well as the approximations can be split. The idea of this decomposition is to start from a scale-oriented decomposition and then to analyze the obtained signals on frequency sub bands.

3.1. Choosing the Optimal Decomposition

Based on the organization of the wavelet packet library, it is natural to count the decompositions issued from a given orthogonal wavelet. As a result, a signal of length $N = 2L$ can be expanded in at most $2N$ different ways, the number of binary sub-trees of a complete binary sub tree of depth L.
As this number may be very large, and since explicit enumeration is generally unmanageable, it is interesting to find an optimal decomposition with respect to a convenient criterion, computable by an efficient algorithm. A minimum of the criterion is needed.
The best basis algorithm described in Wickerhauser (1994) uses a minimum entropy criterion and gives the most concise description for a signal for the dictionary in hand. The application of the best basis search for the wavelet packet dictionary is equivalent to an optimal filtering of the signal.
For any given signal, the best basis algorithm decides which base represents the signal more efficiently. A single wavelet packet decomposition gives a lot of bases from which you can look for the best representation with respect to a design objective. This can be done by finding the "best tree" based on an entropy criterion.
Computation of the best tree for a given entropy, computes the optimal wavelet packet tree. In general you will have to refine your threshold by trial and error so as to optimize the results to fit your particular analysis and design criteria.
The wavelet packets can be used for numerous expansions of a given signal. Then the most suitable decomposition of a given signal with respect to an entropy-based criterion is selected.
Then adaptive filtering algorithms with direct applications in optimal signal coding and data compression are produced.
Comparisons with other methods of analysis such as wavelet analysis using harmonic wavelets and classic Fourier analysis have been applied. As expected, this adaptive method gives better results.
Advanced time-frequency analysis techniques are used to observe the shifting of the natural frequencies of nonlinear structures and the changes on modal damping.

4. PROPOSED METHOD

Generally, the main idea of the proposed method is to use wavelet packet theory. A distinct feature of the proposed method is that it is easy to impose the shape of the envelope function which is derived from various records.
It is noted that records have been scaled with the maximum acceleration equal to g. Besides, response spectra are calculated by applying Naeim method with ζ=0.05: (Naeim - 1999).
In this study, coefficients of wavelet packet and inversion are calculated with Mallat Discrete Wavelet Transform (DWT) and (IDWT), respectively.
An entropy-based criterion is used to select the most suitable decomposition of a given signal and also An adaptive filtering algorithm, based on work by Coifman and Wickerhauser.(1994)is used.
Such algorithms allow the Wavelet Packet tools to include "Best Tree" features that optimize the decomposition both globally and with respect to each node. In this study the wavelet packet compression procedure is also used which involves four steps:

1.-Decomposition for a given wavelet, compute the wavelet packet decomposition of signal x at level N.
2- Computation of the best tree for a given entropy, compute the optimal wavelet packet tree.
3.-Thresholding of wavelet packet coefficients for each packet (except for the approximation), select a threshold and apply threshold to coefficients. This threshold is based on balancing the amount of compression and retained energy.
The threshold is refined by trial and error so as to optimize the results to fit our particular analysis and design criteria
4- Reconstruction**,** compute wavelet packet reconstruction based on the original approximation coefficients at level N and the modified coefficients.

5. ANALYTICAL SAMPLES

This study has been accomplished for some selected records of Iran (Ramezi 1997) (i.e. Naghan 1977, Tabas 1978). These records were scaled with their peak ground acceleration to 1g. In this section, the proposed method has been applied with MATLAB software (MATLAB 1999) with using wavelet packet base function for earthquake records. In figure 2-3 the results of using this method with comparison by wavelet method for Tabas (in Iran) are shown. Also the wavelet energy spectrum of artificial earthquake Accelerogram of Tabas (in Iran) is shown in figure 4.

6**. CONCLUSION**

In this study, a method of applying wavelet packet transform for generation of artificial accelerograms from pseudo-acceleration response spectra is developed. This method shows with computation of the best tree for a given entropy, the optimal wavelet packet tree is computed to balance the amount of compression and retained energy. By using this method the results can be optimized. The feasibility and reliability of the proposed method have been verified with different earthquakes of Iran.

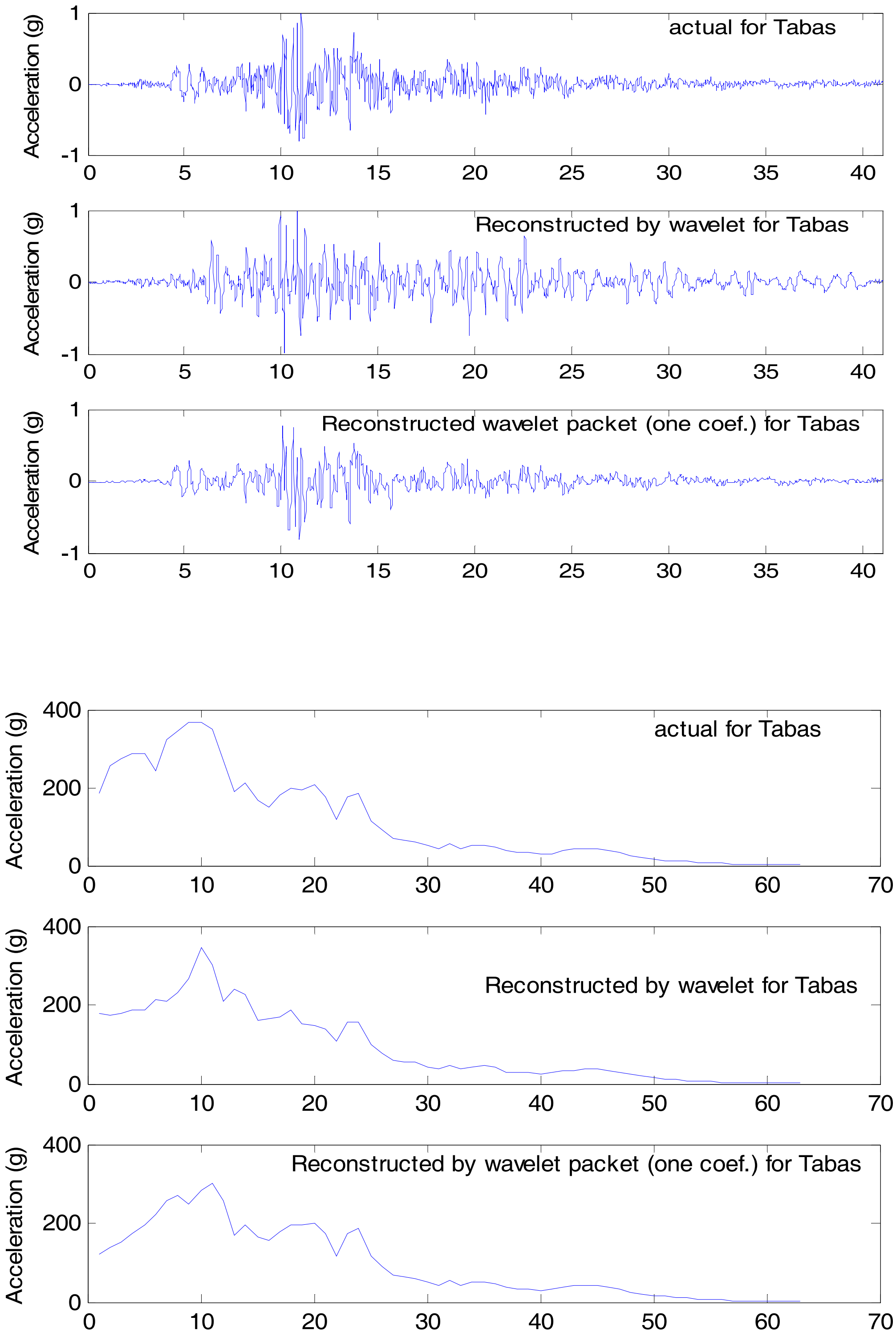

Figure 2 The results of using method for Tabas (Iran)

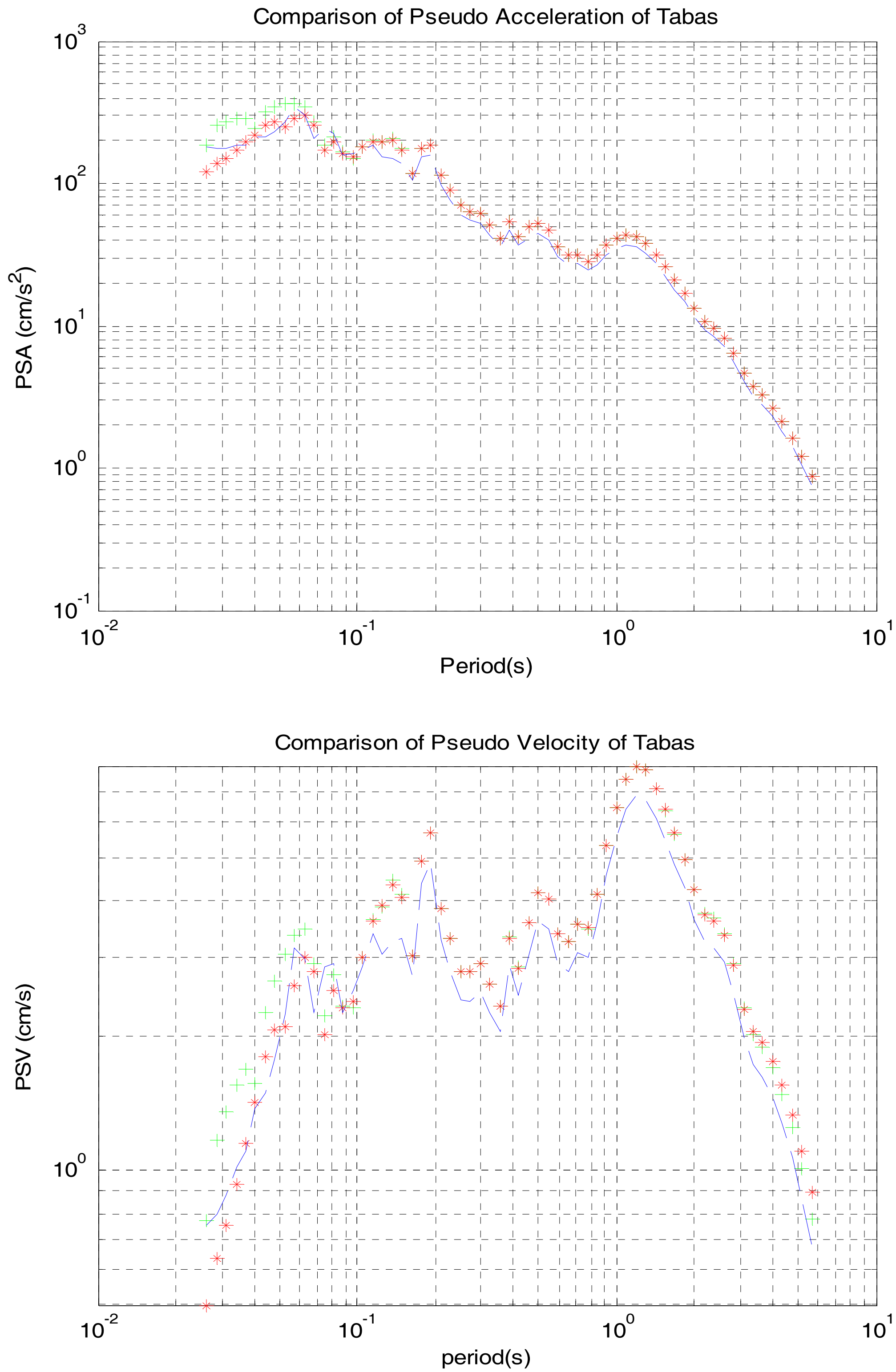

Figure 3 The results of using method in pseudo velocity and pseudo acceleration for Tabas (Iran)

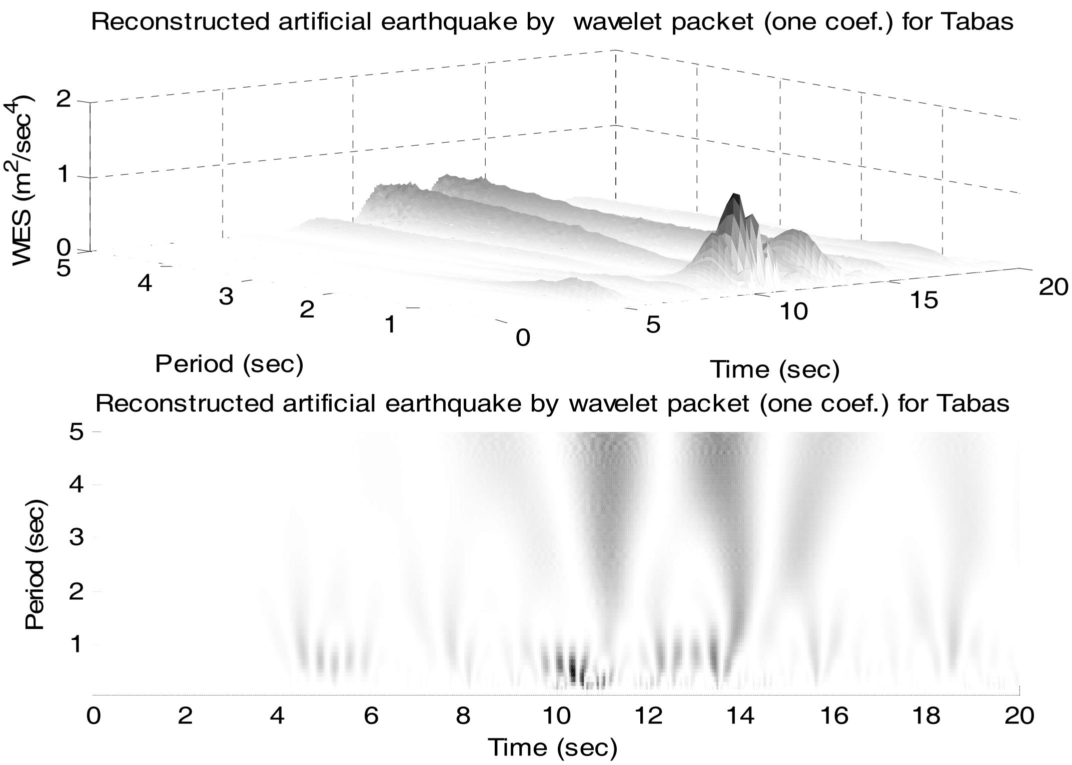

Figure 4 Wavelet energy spectrum of artificial earthquake accelerogram of Tabas (Iran)

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