

# Ground motion estimation based on Wigner distribution using analytic signal wavelets

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## 1. Introduction

Ground motion is a non-stationary time series signal and its synthesis requires consideration of time frequency characteristics. Since Fourier transform does not provide explicit information of the temporal variation of characteristics of the signal, short time Fourier transform (STFT) or wavelet transform are often adopted in generating non-stationary signal. We propose to exploit Wigner distribution in wave synthesis, which has a higher resolution on the time-frequency space than STFT and wavelet analysis.

## 2. Wave synthesis using analytic signal wavelets

Wigner distribution (WD) has a high resolution and satisfies the marginal condition on the time-frequency domain, but it also has 'noisy' cross terms that are generated by the interference of more than one time-frequency components of the original time series. Existence of cross terms obstructs the easy handling of WD. For example, WD are not representable (does not have a corresponding time series signal) unless its cross terms are perfectly consistent. Authors (2001) proposed a method to generate a time series signal from arbitrary (non-representable) WD. The method projects a given WD to the space spanned by WDs of orthogonal wavelet functions. It yields a representable WD that approximates the given WD. Corresponding time series signal can be generated from that WD.

We here propose to use analytic signal wavelet functions in this method. Analytic signal is a complex signal that does not have negative frequency components. We use as an analyzing wavelet an analytic signal that can construct a set of orthogonal wavelets. Adoption of analytic signal wavelets also enables elimination of 'noisy' cross terms of WD among positive frequency components.

## 3. Estimation of time-frequency characteristics of the ground motion at the unobserved station

We propose a scheme to estimate the time-frequency characteristics from those of the observed strong motion records. The procedure is as follows. Firstly, WDs of the observed ground motion records are calculated assuming that they are real parts of analytic signals. The WD of the ground motion at the target site is estimated by morphing those WDs of the observed records. It is also possible to modify the amplitude of WD considering the physical conditions such as the effect of ground condition, epicentral distance, frequency-dependent propagation characteristics. Now WD of the target wave is obtained and one can generate the time series signal using the method shown above.

## 4. Numerical examples

For the purpose of verification of the performance, the proposed scheme is applied to the strong motion records. We select one of the strong motion records obtained in the 1999 Chi-chi Earthquake as a target, and its time history is estimated from two other strong motion records obtained in the same event by using the proposed scheme. The target site is located halfway between the two observation stations. WD of the ground motion at the target site is interpolated by warping the WDs of the two other records. Reference points for warping are determined considering Choi-Williams distribution (CWD) of these records. (CWD has smaller cross terms than WD and it can portray clearly time-frequency characteristics.) Simulated ground motion has large amplitude in the relatively high frequency area in the early stage and low frequency components become dominant in the later part, which shows good agreement with those of the observed strong motion.

We also synthesize the target wave by adjusting the amplitude of WD depending on the epicentral distance in the morphing process. It yields the time history that is more close to the observed records than the above-mentioned wave whose WD is linearly interpolated. This indicates that the proposed scheme successfully generate the target wave taking physical conditions into consideration.