Time-dependent Monitoring of Near-surface and Ground Motion Modeling: Developing New Data Processing Approaches based on Music Information Retrieval (MIR) strategies

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Abstract:

Seismology, like many scientific fields, e.g., music information retrieval and speech signal processing, is experiencing exponential growth in the amount of data acquired by modern seismological networks. In this thesis, I take advantage of the opportunities offered by "big data" and by the methods developed in the areas of music information retrieval and machine learning to better predict the ground motion generated by earthquakes and to study the properties of the surface layers of the Earth.

In order to better predict seismic ground motions, I propose two approaches based on unsupervised deep learning methods, an autoencoder network and Generative Adversarial Networks. The autoencoder technique explores a massive amount of ground motion data, evaluates the required parameters, and generates synthetic ground motion data in the Fourier amplitude spectra (FAS) domain. This method is tested on two synthetic datasets and one real dataset. The application on the real dataset shows that the substantial information contained within the FAS data can be encoded to a four to five-dimensional manifold. Consequently, only a few independent parameters are required for efficient ground motion prediction. I also propose a method based on Conditional Generative Adversarial Networks (CGAN) for simulating ground motion records in the time-frequency and time domains. CGAN generate the time-frequency domains based on the parameters: magnitude, distance, and shear waves velocities to 30 m depth (V_{S30}). After generating the amplitude of the time-frequency domains using the CGAN model, instead of classical conventional methods that assume the amplitude spectra with a random phase spectrum, the phase of the time-frequency domains is recovered by minimizing the observed and reconstructed spectrograms.

In the second part of this dissertation, I propose two methods for the monitoring and characterization of near-surface materials and site effect analyses. I implement an autocorrelation function and an interferometry method to monitor the velocity changes of near-surface materials resulting from the Kumamoto earthquake sequence (Japan, 2016). The observed seismic velocity changes during the strong shaking are due to the non-linear response of the near-surface materials. The results show that the velocity changes lasted for about two months after the Kumamoto mainshock. Furthermore, I used the velocity changes to evaluate the in-situ strain-stress relationship. I also propose a method for assessing the site proxy "V_{S30}" using non-invasive analysis. In the proposed method, a dispersion curve of surface waves is inverted to estimate the shear wave velocity of the subsurface. This method is based on the Dix-like linear operators, which relate the shear wave velocity to the phase velocity. The proposed method is fast, efficient, and stable.

All of the methods presented in this work can be used for processing "big data" in seismology and for the analysis of weak and strong ground motion data, to predict ground shaking, and to analyze site responses by considering potential time dependencies and nonlinearities.