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# GLM-based automatic picking of waveforms

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Large high-quality and data sets are required for accurate earthquake location, to better define seismogenic volumes and enhance the resolution of crustal and upper mantle structures in seismic tomography. Large data sets are generally derived from routine hand-picking and are certainly affected by inconsistencies and blunders. Manual picking of the arrival times of the major body waves phases on full seismograms is a very time consuming activity, practically unusable for these studies, where typical dat sets consists of thousands to tens of thousands of seismograms.
Technique for automatic detection of first-arrival on continuous seismic records have been studied for over thirty years, this being one key issue for improving the efficiency of automatic seismic network.
These are mainly based on STA/LTA algorithms applied to signal envelopes (Allen, 1978, 1982; Baer and Kradolfer). Recent picking tecniques are based on the quantification of some attributes of the signal, instantaneous or related to a sliding time window like amplitude, frequency or polarization, and have been applied to single attributes or to smoothed combinations of them. Some authors (Morita and Hamaguchi, 1984; Takanami and Kitagawa, 1988; Kushnir et al., 1990; Takanami and Kitagawa, 2003) modeled seismic time series as a multiple AR process, using the Akaike Information Criterion (AIC). Other seismologist (Der and Shumway, 1999 ) have tested the performance of the CUSUM algorithm (Basseville and Nikiforov 1993) in the first arrivals picking. Approches based on Pattern Recognition (Klumpen and Joswig, 1993) and Neural Networks (Dai and MacBeth 1995, 1997), window threshold detection (Willis and Toksoz., 1983; Coppens, 1985) and variation in fractal dimension (Boschetti et al., 1996) have been also used.
We develop an automatic picking method based on the fit of a generalized linear regression model (GLM) for detecting change-points in the variance of heteroscedastic Gaussian variables, with piecewise constant variance function, associated to the sequence of the major seismic phases in a seismogram. In particular, we propose a breakpoint detection procedure for changes in variation assuming that the variance function can be described by a piecewise constant function with segments delimited by unknown change-points; moreover the method discard the spurious change-points on the basis of a generalized version of the BIC, extending the cumSeg procedure proposed by Muggeo and Adelfio (2011). Although there are many circumstances in which testing for change in variance is crucial, such as waveforms of earthquakes picking, the problem of variance change-point detection has not been widely considered in the literature, but for few papers focusing in autoregressive time-series models (Wichern et al., 1976; Wang and Wang, 2006; Zhao et al., 2010, e.g.), most neglecting the problem of multiple change-points in part because of the difficulty in handling computations.
The proposed simple and efficient method allows to detect and select unknown multiple change-points on the basis of a very basic GLM-based procedure. Simulations have shown good performance of the proposed approach, such as a sample size increases, mean squared errors of the detected number of change-points decrease. Finally, applications to real seismograms provide efficient and fast arrivals picking, detecting multiple change-points that are reasonably identifiable with particular source signal generation.

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