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Strategies for reliable automatic onset time picking of acoustic emissions and of ultrasound signals in concrete

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Abstract

Determining the onset of transient signals like seismograms, acoustic emissions or ultrasound signals is very time consuming if the onset is picked manually. Therefore, different approaches exist, especially in seismology. The concepts of the most popular approaches are summarized. An own approach adapted to ultrasound signals and acoustic emissions, based on the Akaike Information Criterion (AIC), is presented. The AIC-picker is compared to an automatic onset detection algorithm based on the Hinkley criterion and also adapted to acoustic emissions. Manual picks performed by an analyst are used as reference values.

Both automatic onset detection algorithms are applied to ultrasound signals which are used to monitor the setting and hardening of concrete. They are also applied to acoustic emissions recorded during a pull-out test. The AIC-picker produces sufficient reliable results for ultrasound signals where the deviation from the manual picks varies between 2% and 4%. Concerning acoustic emissions, only 10% of the events result in a mislocation vector greater than 5 mm. It can be shown that our AIC-picker is a reliable tool for automatic onset detection for ultrasound signals and acoustic emissions of varying signal to noise ratio.

Keywords: Onset detection; Automatic picker; Akaike Information Criterion; Hinkley criterion; Acoustic emission; Ultrasound

1. Introduction

The determination of the onset time of a transient signal is an important task in many fields of science. Seismology and acoustic emission measurements are related fields which use the phenomenon of stored elastic energy being released as elastic waves due to sudden fracturing in a rigid body [19]. Due to the same demand of exact onset time determination for 3-dimensional localisation, in particular a strong relation between seismology and acoustic emission analysis exists.

The accurate onset time determination carried out visually by an operator or automatically by a picking algorithm depends on the onset definition itself. Leonard [15] describes the true onset time of a seismic phase as the moment when the first energy of a particular phase arrives at a sensor. However, this definition is applicable to elastic waves in nearly all media. The onset time is usually picked as the point where the difference from the noise occurs first, although an experienced analyst will often extrapolate slightly back into the noise [15]. These are also the requirements to a reliable automatic picker.

With some modifications, the algorithms used in seismology can be applied to acoustic emissions and ultrasound signals. Furthermore, the number of recorded acoustic emissions can be up to several thousands during one test. Therefore, it is also obvious that the automation of the onset determination is necessary.

In this paper, we refer to the convention suggested by Allen [2], i.e. pickers are algorithms used to estimate the onset time of a phase and detectors are algorithms used

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to detect a phase (phase means e.g. longitudinal or transversal wave).

In seismology, a variety of automatic onset time picking approaches are applied. Two general procedures can be distinguished. On the one hand, the whole signal is scanned for the onset which we call global strategy. On the other hand, a certain region is preselected in which the onset is then determined exactly which we call iterative strategy. The main trends will be summarized in the following.

The simplest form for onset picking is to use an amplitude threshold-picker. However, small amplitude signals and/or signals with a high noise level are not valuable for a pure threshold approach [21]. A widespread approach finally using a dynamic threshold, which is not applied to the raw signal, is the so called STA/LTA (STA Short Term Average, LTA Long Term Average) picker by Baer and Kradolfer [3]. A characteristic function based on the signal's envelope is defined. Here, the STA measures the instant amplitude of the signal and the LTA contains information about the current average seismic noise amplitude. The difference between STA and LTA function is further defined by multiplying the characteristic function with frequency dependent parameters. Earle and Shearer [6] chose a similar approach with a different envelope function. Due to the fact that signal and noise of acoustic emissions in concrete are often to be found in the same frequency range (20 kHz up to 300 kHz), the STA/LTA picker would not produce accurate enough results.

Joswig [11] combined the STA/LTA trigger with a sonogram analysis of the seismic signal. This approach has not been tested on ultrasound signals and acoustic emissions yet.

Dai and MacBeth [5] used an artificial neural network for automatic picking of local earthquake data. The network is trained by noise and p-wave segments. Furthermore, not the windowed segment of the raw signal is passed to the network but the modulus of the windowed segment of the signal. The output of the network consists of two values which are parameters of a function that highlights the difference between the actual output and ideal noise. The disadvantage of this approach is the relative long time that is needed for the calculation of the onset time.

Modelling the signal as an autoregressive process is another approach for onset time determination. A detailed description of theory and application for seismic signals can be found in Sleeman and van Eck [18], Leonard [15] and Zhang et al. [23]. Akaike [1] as well as Kitagawa and Akaike [12] showed that a time series can be divided into locally stationary segments, each modelled as an autoregressive process (Akaike Information Criterion). Concerning the application to seismology, a seismic signal including the onset and a first estimate of the onset time is needed. The intervals before and after the onset time are assumed to be two different stationary time series. For a fixed order autoregressive process the point at which the Akaike Information Criterion is minimized, determines the separation point of the two time series (noise and signal) and therefore the onset point [18].

Concerning acoustic emissions and ultrasound signals, we adopted the principle of the autoregressive AIC-picker for an automatic onset detection procedure. The results of our autoregressive AIC-picker were then compared to manual picks and to another auto-picker. This auto picker was developed for acoustic emissions and is based on the Hinkley criterion [9]. Details about our approach and the results will be shown in the following.

2. Adapted auto-pickers for acoustic emissions and ultrasound signals

2.1. Autoregressive AIC-picker

Acoustic emissions and seismograms have many similarities, however, there also exist several differences which do not allow the application of exactly the same picking algorithms in both fields. Concerning seismic events for instance, signal and noise are usually located in different frequency ranges. Therefore, we present an adapted automatic picker based on the AIC. It produces reliable results for acoustic emissions and for ultrasound signals with a relative high success rate. The problem concerning acoustic emissions and ultrasound signals in concrete is that signal and noise are often in the same frequency range. Furthermore, due to failure processes in the tested specimen, the signal to noise ratio of acoustic emissions is generally not constant during an experiment. Zang et al. [22] successfully applied an automatic onset determination algorithm similar to the STA/LTA picker to acoustic emissions from rock samples. However, acoustic emissions from rock samples are mostly to be found in a higher frequency range than acoustic emissions from concrete. Fig. 1 shows two examples of signals of concrete of one test with a different signal to noise ratio. The use of anti-causal, zero phase filters or the careful use of the wavelet transform can help to improve the signal to noise ratio. Nevertheless, a reliable automatic picker which can handle data of varying quality is needed.

An autoregressive AIC-picker gives picks (picks means determined onset times) of higher quality if the AIC is only applied to a part of the signal which contains the onset, of course [23]. Therefore, the onset is prearranged by using the complex wavelet transform or the Hilbert transform. Both transforms lead to a certain envelope of the signal (Fig. 2). The Hilbert transform $\overline{R}(t)$ of a real time dependent function $R(t)$ is defined as [4]: