ARRIVAL TIME DETECTION IN THIN MULTILAYER PLATES ON THE BASIS OF AKAIKE INFORMATION CRITERION

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Abstract

The information of first-arrival time of acoustic emission (AE) signal is important in event location, event identification and source mechanism analysis. Manual picks are time-consuming and sometimes subjective. Several approaches are used in practice. New first arrival automatic determination technique of AE signals in thin metal plates is presented. Based on Akaike information criterion (AIC), proposed algorithm of the first-arrival detection uses the specific characteristic function, which is sensitive to change of frequency in contrast to others such as envelope of the signal. The approach was tested on real AE data recorded by a four-channel recording system. The results were compared to manual picks and to other AIC approach. It is shown that our two-step AIC picker is a reliable tool to identify the arrival time for AE signals.

Introduction

The precise determination of the arrival time of transient signals like AE, seismograms or ultrasound signals is one of the fundamental problems in non-destructive testing and geophysics. The information of this time is important in event location, event identification and source mechanism analysis. Manual picks are time-consuming and sometimes subjective, especially in the case of large volumes of digital data. Various techniques have been presented in the literature and are routinely used in practice, such as a passing the threshold level, analysis of the LTA/STA (long term average/short term average), high order statistics or artificial neural networks.

Modeling the signal as an autoregressive process (AR) is another approach for onset time determination. It is based on the assumption that the signal can be divided into locally stationary segments and the intervals before and after onset are two different stationary processes [1]. On the basis of this assumption, an autoregressive Akaike information criterion (AR-AIC) has been used to detect P and S phases [1-3] in seismology. For AR-AIC picker, the order of the AR process must be specified by trial and error and the AR coefficients have to be calculated for both intervals. In contrast, Maeda [4] calculated the AIC function directly from seismogram without using the AR coefficients. For time series x of length N, the AIC is defined as

\[ AIC(k) = k \log(\text{var}(x[1,k])) + (N-k-1) \log(\text{var}(x[k+1,N])) \]  

where \(k\) is range through all time of time series. However, the AIC picker does not perform well, if the signal to noise ratio is low and the arrival is not evident. Further, for AIC picker to identify the proper arrival, a limited time window of the data must be chosen [3].

Although AE and seismograms are similar to each other for first view, there also exist several differences. In seismology the signal and noise are usually located in different frequency range. AE signal and noise are often in the same frequency range and also signal-to-noise ratio is gener-
ally not constant during experiment. Kurz et al. [5] successfully applied an adapted automatic AIC picker based on Maeda’s relation to AE from concrete and used the complex wavelet transform and Hilbert transform as characteristic function instead of the signal. Both these transforms lead to a certain envelope of the signal. The advantage of the envelope by wavelet transformation is that it can be calculated only for one frequency, while most of the noise of the signal is found in different frequencies. However, if two or more signals of different amplitude and frequency superpose each other, the envelope calculated by the Hilbert transform should be used.

In our case, the signal is described by the specific characteristic function, which is used as input data for AIC. This characteristic function is sensitive to change of frequency in contrast to others such as envelope of the signal, which indicates only change in amplitude of signal. The approach was tested on real AE data and compared to manual picks as well as to Kurz’s AIC approach.

**Two-step AIC Picker**

The performance of the picker depends strongly on characteristic function. The arrival time is indicated by a change in the frequency, or amplitude, or both, in the time series, and characteristic function must respond to this change as rapidly as possible and, ideally, should enhance the change [6]. The absolute value function $CF(i) = |x(i)|$ is easy to compute and the most widely used (amplitude threshold picker). The square function $CF(i) = x(i)^2$ enhances the amplitude changes but not frequency changes. For seismogram threshold picker, Allen [6] used a function,

$$ CF(i) = x(i)^2 + K (x(i) - x(i-1))^2 $$

where $K$ is a weighting constant that varies with sample rate and stationary noise characteristics. Unfortunately, we discovered that these characteristic functions are not so effective for our case. We found that our AIC picker succeeds with following function,

$$ CF(i) = |x(i)| + R |x(i) - x(i-1)| $$

where $R$ is a constant specified by trial and error; for our case $R = 4$. This characteristic function is sensitive to change of frequency in contrast to others such as envelope of the signal.

During one experiment, an AE measurement system can recognize and record up to several thousand AE signals. The length of one AE signal and threshold level is defined by researcher in advance. If we consider the facts mentioned above about AIC pickers, the choice of correct time window is a crucial factor for the identification of proper arrival. Ideally, the time window starts in non-informative part of AE signal (noise) and ends in informative part of AE signal (real signal).

Our proposal of the first-arrival detection solves this problem. Figure 1 presents visual description of individual stages of our algorithm. The algorithm shortens the time interval of the original time window in Fig. 1a. The beginning of signal is presumed as non-informative part and it is not changed. The global maximum of the original signal in absolute value is found, $t_{MAX}$. This time plus time delay $\Delta t_{AM}$ is considered the end of informative part of AE signal. We set the $\Delta t_{AM} = 20 \mu s$, which is reasonable for material of our interest. Mathematically, this can be defined for signal $x$ of length $N$ with time step $\Delta t = 0.1 \mu s$ as
\[ i_{\text{max}} = i: \quad |x(i)| = \max(|x|) \quad \text{where} \ x = \{x(i) | i = 1, \ldots, N\} \]

\[ x_{\text{NEW}} = \{x_{\text{NEW}}(i) | i = 1, \ldots, (i_{\text{max}} + 200)\} \]

where \( x_{\text{NEW}} \) is results of shortening of time window.

Fig. 1. Visual description of our two-step AIC picker. (a) Definition of new time interval, (b) Characteristic function, (c) Determination of first estimation of arrival time and focus on its neighborhood, (d) Determination of final arrival time, (e) Result.
Our algorithm is a two-step process. First, the characteristic function Eq. 3 is computed on shortened signal (Fig. 1b) and AIC picker based on Maeda’s relation Eq. 1 is applied on this CF. The global minimum of AIC function determines the first estimation of the arrival time (Fig. 1c). In second step, we focus on neighborhood of first estimation (Fig. 1c). The time interval is changed to start at \( \Delta t_{FB} \) before first estimation and to end at \( \Delta t_{FA} \) after first estimation. For our case, \( \Delta t_{FA} = 10 \mu \text{s} \) and \( \Delta t_{FB} = 30 \mu \text{s} \) were found by trial and error. The AIC picker is applied once again on CF in this shortened time interval (Fig. 1d). The global minimum of recalculated AIC function defines the arrival time of AE event, as can be seen in Fig. 1e.

**Experiment**

Acoustic emission is one of the methods describing behavior and properties of materials under various conditions. Considering the nature of AE, many spurious events can occur during an experiment and represent potential errors in final conclusions. In our case, the localization is used to eliminate this possible error.

The approach was tested on real AE data. Figure 2 presents measurement set-up of this tensile test of 25-layered SPCC/SUS420J2 thin plate with four sensors, which were located in one line. The location of AE event is estimated by one-dimensional hyperbolic localization by times of first arrival. AE measurement system called Continuous Wave Memory [7] was used to recognize AE events by 15-mV threshold and to store every event in 100 \( \mu \text{s} \) time length. Continuous Wave Memory sampled data at a rate of 10 MHz by 12-bit A/D converter. The data were filtered numerically by a 4th-order Butterworth high-pass filter with cut-off frequency of 100 kHz.

![sensors](image)

**Fig. 2. Measurement set-up of tensile test.**

**Results and Discussion**

In the test, the 25 AE events from center region of a specimen were chosen for comparative investigation. It represents 100 AE signals. Arrival times of these chosen events were determined manually as well as automatically using our approach and Kurz’s approach with envelope calculated by Hilbert transform [5]. The signal-to-noise ratio (SNR) of the chosen event varied according to the test stage the individual event occurred.

Figure 3 shows that the localized events obtained with arrival times of our two-step AIC picker are all situated relatively close to the events localized with the arrival times determined manually. The events localized using arrival times determined by Kurz’s AIC picker are not in such proximity to manually picked events. The explanation is within reach. The mean of differences between manual picks and Kurz’s AIC picker is 2.7 \( \mu \text{s} \), but maximal difference is 18 \( \mu \text{s} \).
(Fig. 5). In case of two-step AIC picker (Fig. 4), the mean is 0.2 \( \mu \text{s} \) and the maximum is 2.4 \( \mu \text{s} \) only.

![Fig. 3. Localization error: comparison of two-step AIC picker with Kurz AIC picker.](image)

![Fig. 4. Histogram of differences between manual picks and automatic picks by two-step AIC picker and its corresponding signal-to-noise ratios (circles).](image)

We found that 89\% of arrival times were determined by our approach with deviation less than 0.5 \( \mu \text{s} \), whereas in case of Kurz’s AIC picker it was 41\%. The examples of the first-arrival determination for varying signal-to-noise ratios are shown in Fig. 6.

**Conclusion**

A new automatic determination technique of the first-arrival times of AE signals is presented for thin metal plates. Based on Maeda’s relation, the proposed algorithm of the first-arrival
detection uses the specific characteristic function. This characteristic function CF is sensitive to change of frequency in contrast to others such as envelope of the signal.

Fig. 5. Histogram of differences between manual picks and automatic picks by Kurz’s AIC picker and its corresponding signal-to-noise ratios (circles).

Fig. 6. Examples of first-arrival detection for varying signal-to-noise ratios in first test.

The proposed algorithm shortens the time window of an AE signal so that it ends in the informative part of the signal. The characteristic function is computed on the shortened signal and AIC picker is applied. The global minimum of AIC function determines the first estimation of the arrival time. The time window is shortened again and focused on the neighborhood of first estimation. The AIC picker is applied once again on CF in this shorter time interval. The global minimum of recalculated AIC function defines the arrival time of the AE event.
The approach was tested on a tensile test of a 25-layered SPCC/SUS420J2 thin plate. From the test, 25 AE events were chosen. Arrival times of these AE events were determined manually as well as automatically using our approach and Kurz’s approach. Although we and Kurz et al. use the same Maeda’s equation, the approaches differ in characteristic function. The choice of characteristic function is a crucial factor for the first-arrival detection.

The comparative investigation shows that 89% of arrival times were determined by our two-step AIC picker with deviation less than 0.5 µs and 96% of arrival times were determined by our two-step AIC picker with deviation less than 1 µs. It shows that the two-step AIC picker is a reliable tool for automatic identification of the arrival times for AE signals of varying signal-to-noise ratios.

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