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# New automatic localization technique of acoustic emission signals in thin metal plates

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ABSTRACT

In acoustic emission (AE) measurement, the information of the arrival time is very important for 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 amplitude threshold, analysis of the long-term average/short-term average (LTA/STA), high-order statistics or artificial neural networks.

A new automatic determination technique of the first arrival times of AE signals is presented for thin metal plates. Based on Akaike's information criterion, proposed algorithm of the first arrival detection uses a specific characteristic function, which is sensitive to change of frequency in contrast to others such as envelope of the signal. The approach is applied to data sets of three different tests. Reliable results show the potential of our approach.



## 1. Introduction

The precise determination of the arrival time of transient signals like AE, seismograms or ultrasound signal is one of the fundamental problems in non-destructive testing and geophysics. The information of this time is very important for event location, event identification and source mechanism analysis.

The accurate first arrival determination is carried out visually by an operator or automatically by an algorithm and it depends on the first arrival definition itself. It can be described as the moment when the first energy of a particular phase arrives at a sensor or as a point where the difference from the noise occurs first [1]. These descriptions are also requirements to reliable automatic picker.

With some modification, the methods used in seismology can be applied to AE. The number of recorded AE signals can be up to several thousands during one test. It represents huge amounts of data, which call for automatic determination of first arrival without human intervention by sophisticated approaches. The reason is simple, manual picks are time-consuming and sometimes subjective, especially in the case of large volumes of digital data.

Allen [2] described picker as an algorithm, which is used to estimate the arrival time a phase, and described detector as an algorithm, which is used to detect a phase (phase means e.g., longitudinal, transversal or Lamb wave). We refer to this convention in this paper. In our case, the proposed picker is designed to determinate the arrival time of first phase in AE signal (it means first arrival time).

In the past few years, several approaches were used for first arrival determination. An amplitude threshold picker is the simplest one of them. However, the signals with low signal-to-noise ratios (SNR) are not suitable for a pure threshold approach [3]. Baer and Kradolfer [4] published a widespread approach based on short-term average to long-term average ratio (STA/LTA) for purpose of usage in seismology. It was not applied on the raw signal but on the characteristic function, which is defined as an envelope of the signal. The STA measures the instant amplitude of the signal and LTA contains information about the current average noise amplitude. The result is defined as time in which the STA/LTA function reaches predefined threshold level. Earle and Shearer [5] chose a similar approach with a different envelope function. Unfortu-

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nately, in AE the signal and noise can be often found in same frequency range 20 kHz–1 MHz, STA/LTA picker would not be enough accurate [6].

Wang and Teng [7] used artificial neural network for real time seismology. The network is trained by STA/LTA time series. The output of network sets the threshold level for STA/LTA function. Dai and MacBeth [8] also used artificial neural network, but it is trained by noise and P-wave segments. The modulus of the windowed segment of the signal is passed to the network. The output of the network consists of two values, which are parameters of a function that highlights difference between the actual output and ideal noise. Long calculation time and suitable selection of learning data are two main problems of this approach.

An approach based on high-order statistics (HOS) was successfully tested by Saragiotis [9] on real seismic data. Lokajicek and Klima [10] proved that the HOS can also be successfully used in the determination of the first arrival time on AE data. This approach is applicable when the recorded signal converts from a random distribution to non-random one. On the other hand, this approach is not suitable for determination of arrival time of multi-path signals, since only first arrival time can be determined, and times of following arrivals would be very probably hidden in the tail of the previous signal.

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 [11]. On the basis of this assumption, an autoregressive Akaike information criterion (AR-AIC) has been used to detect P and S phases [11–13] 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 [14] calculated the AIC function directly from signal, without using AR coefficients. 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 [13].

In our case, the signal is characterized by a specific function, which is used as input information for AIC picker. 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 a signal. The approach was applied to data sets of three different tests. It will be shown that our two-step AIC picker is a reliable tool to identify the arrival time for AE signals of varying signal-to-noise ratios.

## 2. Previous AIC pickers

As mentioned above, standard AR-AIC approach supposes that a signal can be divided into locally stationary segments each modeled as an AR process. The intervals before and after the arrival time are premised on two different stationary time series [11].

### 2.1. AIC pickers in seismology

Sleemen and van Eck [11] divided the time series into deterministic (forward and backward prediction models) and non-deterministic part, see Fig. 1a. The AR coefficients of forward and backward models are computed in corresponding deterministic term. The variances of prediction errors of models are computed for every point of non-deterministic part and are used in the calculation of the AIC. For fixed order AR process the point where the AIC is minimized determines the separation point of the two times series (noise and signal). This approach is known as AR-AIC picker [11,12]. The AIC of two-interval model for signal $x$ of length $N$ is represented as a function of merging point $k$

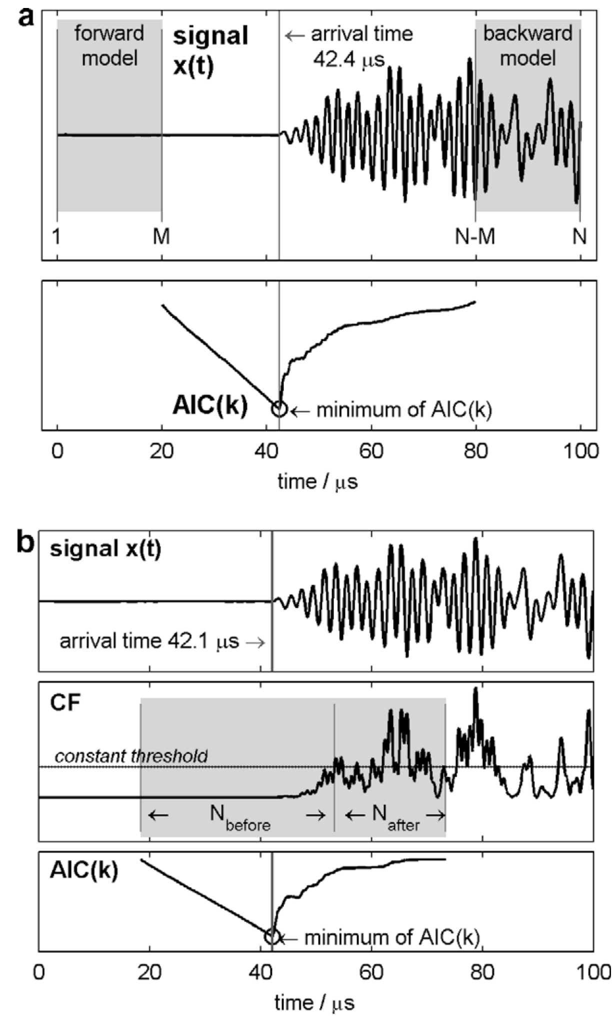


**Fig. 1.** (a) First arrival determination using AR-AIC described by Sleeman and van Eck. (b) First arrival determination using AIC described by Kurz et al.

$$\mathrm{AIC}(k) = (k - M)\log(\sigma_{\mathrm{F}}^2) + (N - M - k)\log(\sigma_{\mathrm{B}}^2) + 2M \qquad (1)$$

where $M$ is the order of an AR process fitting the data, and $\sigma_{\mathrm{F}}^2$ and $\sigma_{\mathrm{B}}^2$ indicate the variance of the prediction errors of forward and backward model. To realize AR-AIC picker, the order of the AR process must be specified by trial and error, and then AR coefficients can be determined by the Yule–Walker equations.

Maeda [14] calculated the AIC function directly from seismogram without using the AR coefficients. For signal $x$ of length $N$, the AIC is defined as

$$\mathrm{AIC}(k) = k\log(\mathrm{var}(x[1,k])) + (N - k - 1)\log(\mathrm{var}(x[k+1,N])) \qquad (2)$$

where $k$ is range through all samples of signal and var($x$[1,$k$]) indicates the variance of corresponding interval from 1 to $k$ of signal $x$.

The AIC global minimum determines the arrival time. If the time window, which considers the signal segment of interest, is chosen properly, the AIC picker is likely to find arrival time accurately. Zhang et al. [3] applied this AIC picker to multiple scales, which are decomposed by wavelet transformation. By comparing the consistency among the picks at different scales, they could determine whether there is an arrival in the current time window or not.

### 2.2. AIC pickers in acoustic emission

AE and seismograms are quite similar to each other. However, there also exist several differences. In seismology the signal and