

## Effect of Sampling Frequency on Acoustic Emission Onset Determination using Fractal Dimension

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**Keywords:** Acoustic Emission, Fractal Dimension, Higuchi's method, Onset Determination, Sampling Frequency

**Abstract** Acoustic emission is the generation of transient stress waves by rapid release of energy from localized sources giving rise to a versatile non-destructive testing technique. Numerous researchers have tried to exploit the fractal nature of acoustic emission for analysis purposes. The analysis of acoustic emission signature typically consists of four stages namely damage detection, damage localization, damage characterization and health prediction. The determination of arrival of first energy of particular phase at sensor, called onset determination, is an important prerequisite for source localization and source mechanism analysis because the accuracy in determination of onset time directly translates to accuracy in source localization and source mechanism analysis. However, the effect of acquisition parameters on the analysis is not well understood. In this present work, the objective is to understand the effect of one of the important acquisition parameters, sampling frequency. Choice of low sampling frequency might lead to loss of signal information while a high sampling frequency increases storage and computation, hence identifying the appropriate sampling frequency is a critical factor for onset determination. In the present work, the effect of sampling frequency on onset determination using fractal dimension has been assessed. Two open source datasets available at Acoustic emission portal set-up by Muravin have been employed for the research work. The first dataset pertains to a concrete beam while the second data is generated from a carbon fiber woven fabric plate. The acoustic emission events have been generated by using pencil lead break tests. The sampling frequency has been varied synthetically from 0.8 to 2.0 MHz in the steps of 100 kHz. The onset is determined for each individual value of sampling acquisition, by detecting change of fractal dimension estimated using Higuchi's method. It has been observed by analyzing the onset values determined at different sampling frequencies that the onset does not always converge to the onset having high accuracy with increase of sampling frequency. This observation has been further verified by calculating Spearman Rank correlation values. Also, the results depict the dependence of technique on material in which emissions are generated. The results may be useful for the design of instrumentation for acoustic emission as well as development of computational methods for analysis.

### Introduction

Acoustic emission is a passive non-destructive technique having applications in versatile areas like structural health monitoring, non-destructive testing and material science [1, 2]. The analysis of acoustic emission involves steps like detection, source localization, damage characterization and health prediction. The onset determination is an important step for AE studies. The accuracy of determined onset directly translates to the accuracy in source localization and source mechanism analysis. The use of acoustic emission technique in practical scenarios makes the use of wireless

equipment necessary. Some solutions related to wireless acoustic emission have been developed [3]. Most wireless solutions employ data aggregation and calculate aggregation functions which are transmitted to base node. The original waveform is lost resulting into limitations on damage characterization. Moreover, the full waveform based systems offer another merits like capability of signal to noise discrimination. The full waveform based wireless systems are rare because acoustic emission in many cases like concrete contains a rich band of frequencies making the data communication difficult. Moreover, the choice of higher sampling frequency can worsen the scenario. The developed solutions' life span and power consumption depends upon the sampling frequency chosen. Therefore it is important to understand the various effects of sampling frequency on analysis in order to optimize the system. In this work, the focus is to analyse the effect of sampling frequency on onset determination. There are various methods for onset picking. Fractals have been employed widely for analysis of acoustic emission because of fractal nature of acoustic emission. In this work, the onset determination using change of fractal dimension will be assessed for effect of sampling frequency.

### Fractal Based Onset Determination

Fractals are objects depicting characteristics like self-affinity, long range dependence, etc. The onset determination problem can be treated as change detection problem with the special attention towards the instant the occurrence of change. Fractals have been employed successfully for many engineering problems [4]. Moreover, several researchers have reported that acoustic emission has fractal nature in temporal as well as spatial domain [5]. It can be expected that the use of ideas derived from fractional order signal processing for acoustic emission problems can be fruitful.

For the purpose of onset determination, fractal dimension is a number sensitive towards structure of signal. Fractal dimension has been employed successfully for change detection in various other areas such as financial time series, electroencephalography, seismology and many more. The difficulties in the calculation of fractal dimension leads to its estimation. Various algorithms such as Burlaga and Klein [6], Higuchi's method [7], Box counting approach, Katz's method [8], multi resolution box counting approach [9] have been developed for the estimation of fractal dimension. In this work, Higuchi's method is employed because of three reasons. Firstly, it can provide physically plausible estimates of fractal dimension. Secondly, it is capable of detecting the change consistently. Lastly, it can handle non-stationary nature of acoustic emission well.

**Higuchi's method:** Higuchi's method is improved version of method proposed by Burlaga and Klein. Consider a finite set of time series observations taken at regular interval:

$$X(1), X(2), X(3), \dots, X(N)$$

From given time series, we construct a new time series first,  $X_k^m$ , defined as follows:

$$X_k^m: X(m), X(m+k), X(m+2k), X(m+3k), \dots, X(m+[N-m/k].k) \quad (m = 1, 2, \dots, k)$$

where  $[ ]$  denotes the Gauss's notation and both  $k$  and  $m$  are integers,  $m$  and  $k$  indicate the initial time and the interval time, respectively. For a time interval equal to  $k$ , we get  $k$  sets of new time series.

Then the length of the curve,  $X_k^m$ , is obtained as follows:

$$L_m(k) = \left\{ \left( \sum_{i=1}^{\left[ \frac{N-m}{k} \right]} |X(m+ik) - X(m+(i-1).k)| \right)^{\frac{N-1}{\left[ \frac{N-m}{k} \right].k}} \right\} / k \quad (1)$$

An average length  $L(k)$  is calculated as the mean of  $L_m(k)$  for  $m=1,2,..k$ . Then  $L(k)$  is calculated for  $k$  ranging from 1 to  $k_{\max}$ . If  $L(k) \propto k^{-D}$ , then the curve is fractal with the dimension  $D$ .

## Datasets employed

The datasets used have been obtained from Muravin et al. [10]. The first experiment used four AE sensors having operating frequency between 100-400 kHz and resonance frequency at 200 kHz. The sensors were mounted on a concrete beam with distance of 0.5 m between each other shown in

Figure 1. External preamplifiers with 60 dB gain were used for amplification of AE signals. Pencil lead break was used as a source of acoustic emission signals. The lead breaks were initiated in 11 different locations and the waveforms were recorded on the AE device. The details of instrumentation parameters used are given in Table:

**Table 1: Instrumentation Parameters used for acquisition of emissions for concrete experiment**

Parameter	Value
Threshold	30dB
Analog Filter Lower Cut-off	20 kHz
Analog Filter Higher Cut-off	400 kHz
Sampling Rate	2 MSPS
Pre-trigger	256 $\mu$ s
Waveform length	15k

The second dataset pertains to composite plate. The carbon fiber plate was composed of carbon tows woven with a plain weave style pre-impregnated with B-staged epoxy resin having 0.2 mm thickness per tow. The plate was of dimensions 650 x 650 x 2 mm<sup>3</sup>. Pencil lead breaks act as AE source.

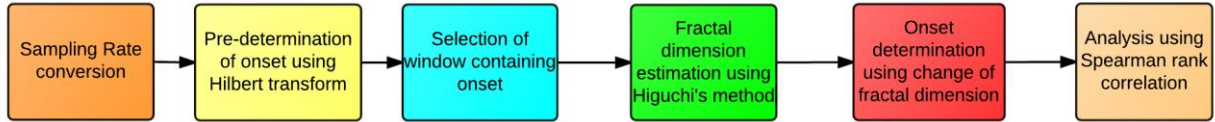


**Figure 1:** (a) Photograph depicting set up for generation of concrete dataset. Four PZT sensors have been attached on concrete beam (b) Photograph depicting set up for Composite experiment. The sensors have been attached at the four corners using clips on the carbon woven fabric plate

The patches in the Figure 1 show the position of pencil lead break tests. Four AE sensors having operational frequency range between 100-400 kHz and resonance frequency at 200 kHz have been used to capture AE signal. The instrumentation parameters are the same as described for concrete dataset except the specifications of analog filter. In this case, analog filter has lower cut-off frequency of 100 kHz and higher cut-off frequency of 200 kHz.

## Methodology

The methodology adopted for research work has been depicted in Figure 2.

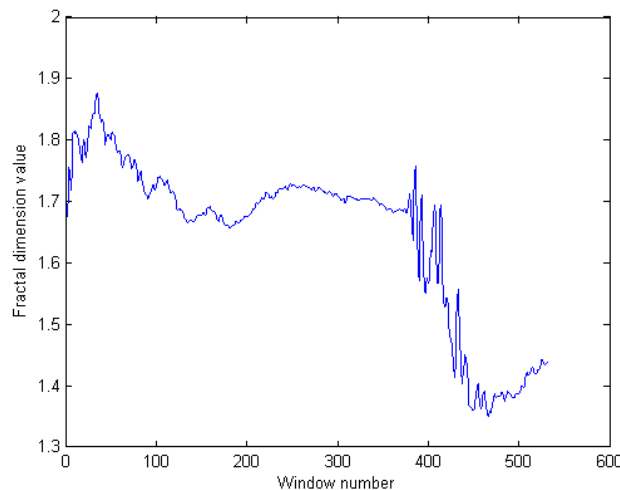


**Figure 2:** Methodology for research work

The onset was pre-determined using Hilbert transform [11]. The initial onset is chosen using thresholding of the complex envelope of signal. The complex envelope is calculated using Hilbert transform. Firstly, time series  $x(t)$  is transformed using Hilbert transform to  $x'(t)$  and then envelope is calculated as

$$e(t) = \sqrt{x(t)^2 + x'(t)^2} \quad (2)$$

Fractal dimension was estimated using Higuchi's method [7]. The implementation was tested with one thousand different fractional Brownian motion signals each of fractal dimension 1.5. The mean of calculated fractal dimension was 1.499906 and standard deviation was 0.007999. The onset is determined by detecting the change in fractal dimension. The variation of fractal dimension has been depicted in Figure 3.

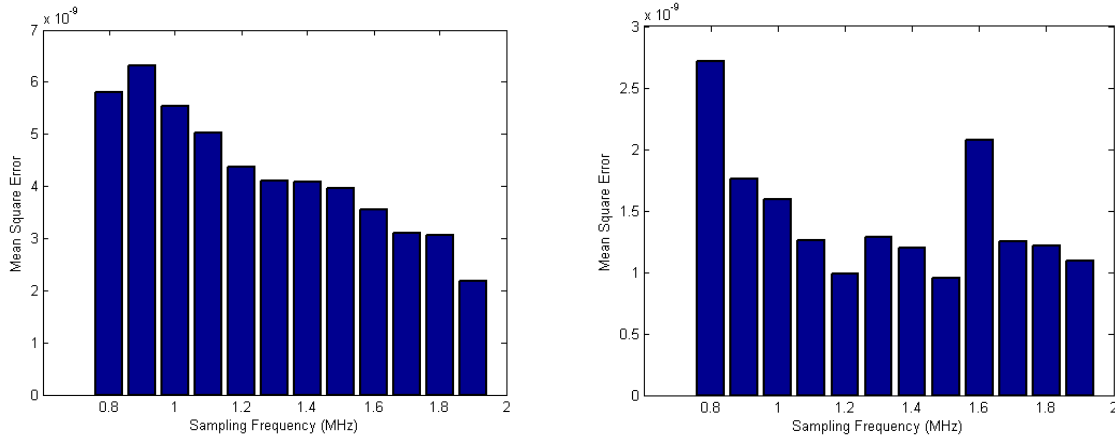


**Figure 3:** Variation of Fractal Dimension. The change in fractal dimension provides the determined onset

To study the effect of sampling frequency, it was varied synthetically from 0.8 MHz to 2.0 MHz in the steps of 100 kHz using Nyquist filter.

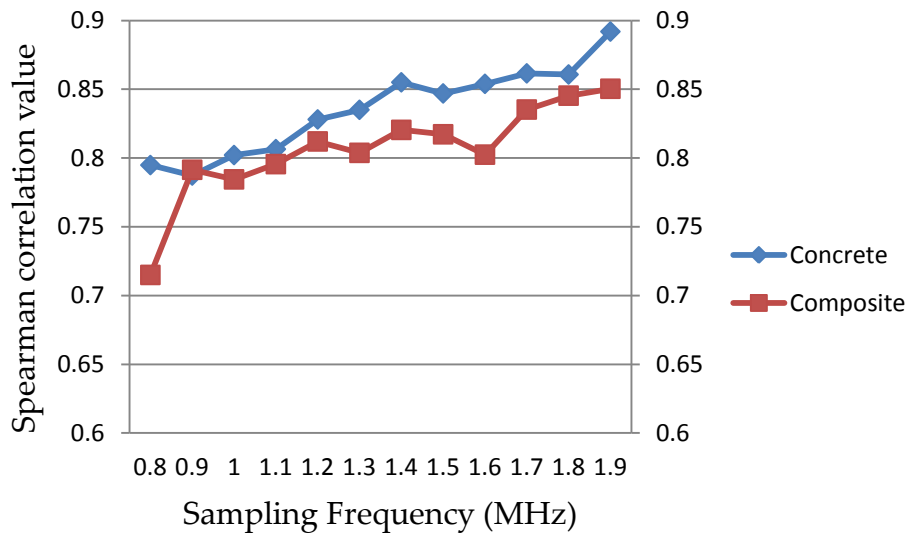
## Results and Discussions

The sampling rate was changed from 0.8 MHz to 1.9MHz in steps of 100 kHz. The onset was determined for each event using fractal based method. The mean square error was calculated as shown in Figure 4. It is seen that mean square error does not decrease steadily as sampling frequency is increased.



**Figure 4:** Mean Square Error for onset calculated using Fractal dimension method (a) Concrete Dataset (b) Composite Dataset

Further, these values were correlated with values determined using AIC at 2 MHz and the values determined using 2 MHz using fractal dimension based method. The correlation of onset values for concrete and composite for different sampling frequencies has been depicted in Figure 5. The correlation values do not depict a steady increase as sampling frequency is increased signifying that the increase in sampling frequency may not always improve the onset determination. Also, the different trends of convergence for the two datasets indicate the possibility of relation between the performance of the algorithm with the material in which emissions are being observed.



**Figure 5:** Correlation of onset values for different sampling frequencies calculated using fractal dimension based method

## Conclusion

It has been observed that the performance of the fractal based onset determination technique does not always improve with increase of sampling frequency. Also, the dependence of the behaviour of the technique on the material in which emissions have been recorded has been observed. In fact, the correlation values obtained for concrete are consistently more than composite material. This signifies the superior performance of fractal based method for concrete material. In future, the analysis will be carried out for more datasets to verify the conclusions further.

## Acknowledgement

This work is partially funded by the CSIR-CSIO network project, I-HEAL and Quick Hire Fellowship by CSIR, New Delhi. The authors thank Dr Boris Muravin, Integrity Diagnostics, Israel for his inputs regarding generated datasets.

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