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Application Of The Short Time Statistical Analysis In Significant Increasing Of The Signal To Noise Ratio Of Infrasound, Acoustic, Hydroacoustic And Seismic Signals

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INTRODUCTION AND MAIN RESULTS

Data recorded for monitoring a global nuclear-test-ban treaty are a mixture of useful signals, ambient and measurement noise. Suppressing these noises and increasing the signal-to-noise ratio is significant task. The presentation describes a way to suppress the mentioned noises, so that by applying the proposed method, the signal-to-noise ratio is increased by more than 20 *dB*. This result is achieved by applying the so-called statistical filter, whose operation is based on the application of fourth-order cumulants. The method enables de-noising of signals with, or without overlapping time intervals.

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Introduction

Starting from the cumulants of the fourth order the statistical domain of the signal analysis is based. This domain enable to analize how statistical properties, or statistical distribution of the signal change in time, that is, to what extent the statistical distribution of the signal deviates from the Gaussian distribution. This approach is justified by the fact that the events we want to analyze are usually caused by the release of some form of energy in a short time interval. In these statistical approach the fourth-order cumulants are used. If a random process is symmetrically distributed, then its third-order cumulant equals zero; hence, for such a process we have to use the fourth-order cumulants. The process which are distributed with Laplace, Uniform, Gaussian, and Bernoulli – Gaussian distributions are symmetric as it is known.

Cumulants, c_n, as a sequence of numbers that efficiently captures the characteristics of the distribution. were explored as early as 1889 by Thorvald Nicolai Thiele, a Danish mathematician and astronomer.

$$c_n = m_k - \sum_{k=1}^{n-1} \binom{n-1}{k-1} c_k m_{n-k} \qquad (1)$$

$m_n = m_n(X) = E[X_n]$ - moment sequence of random variable X,
n – order of cumulant and
k – order of the moment used to calculate cumulant

Methods/Data

Short Time Statistical Analysis constitute statistical domain of the signal analysis. This approach significantly reduce noise level of the primary signal.

The aproach is very similar to the short-time Fourier signal analysis in time-frequency domain where we track how the frequency content of the signal is changing in time, which is of paricular interest in the case of non-stationar signals. The algorithm initially performs segmentation of the initial signal using a rectangular window of a certain width, with or without overlapping. It should be noted that the application of this technique in signal analysis is a computationally very demanding process. Namely, it is necessary to calculate the fourth-order cumulant, see Eq. 1, of each time interval. Depending on the specific need, the number of time intervals can be relatively large, especially if the techique of overlapping time intervals is used. However, with the use of fast modern computers, this problem can be overcome with the necessary optimization, which is achieved by choosing the optimal duration of the time segment.

Results

With this method, noisy signals registered in different areas, such as seismology, acoustic, hydroacoustic, electromagnetic (radar echo signals) and others, were filtered.
In particular, it should be noted that the application of this method of signal filtering made it possible to analyse for the first time, hydroacoustic data recorded at measuring station CTBT IMS H08S, which occurred during the eruption of the Anak Krakatao volcano on 22 Dec. 2018, which until now was not possible using conventional methods for reducing the noise level of hydroacoustic signals.
Noise levels are significantly reduced in all areas, i.e. SNR is significantly increased. Experiments showed that the greatest increase in SNR was noticed in hydroacoustic, followed by acoustic, seismic, and finally in the application to radar signals. This result can be explained by fact that the influence of reverberation on the quality of the registered signals is also expressed in the mentioned order.

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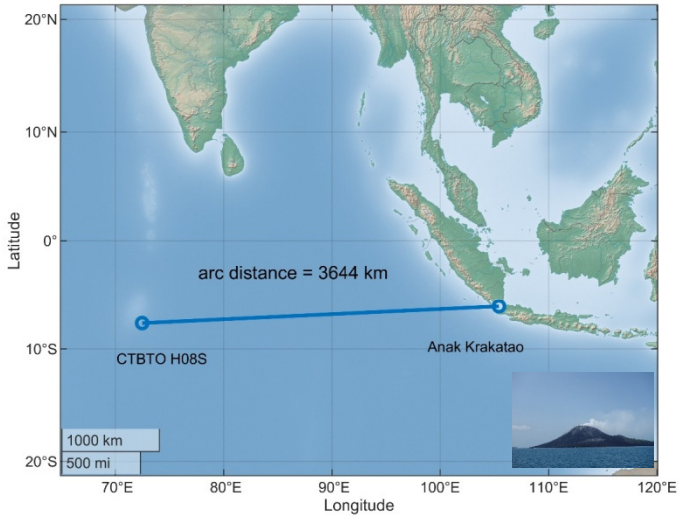
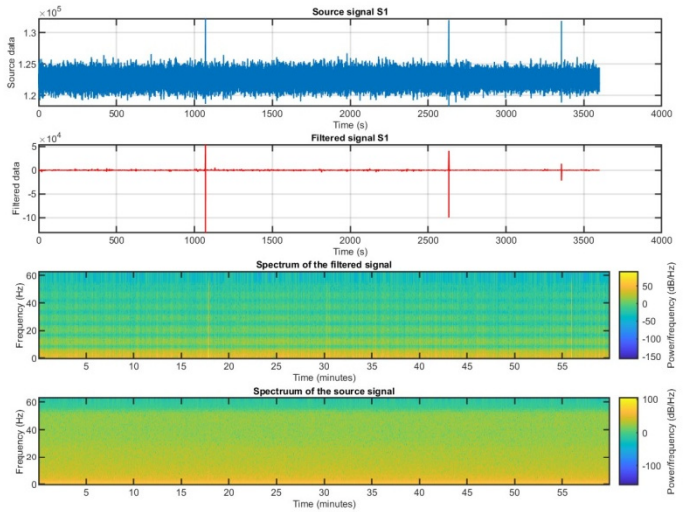
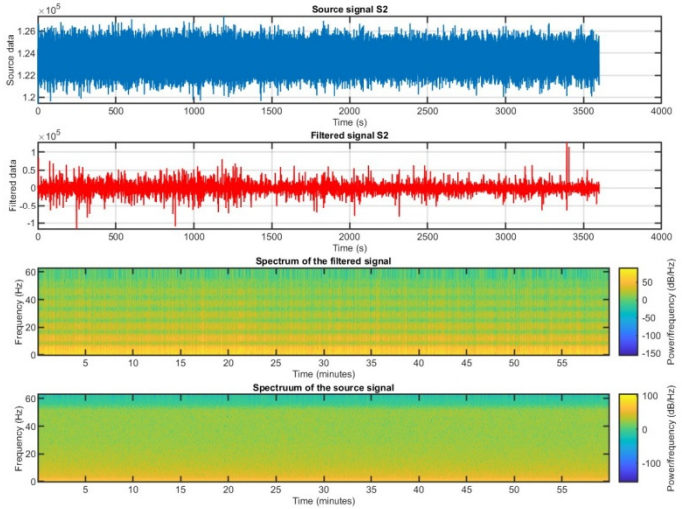
Examples in hydroacoustic originating from seismic disturbances

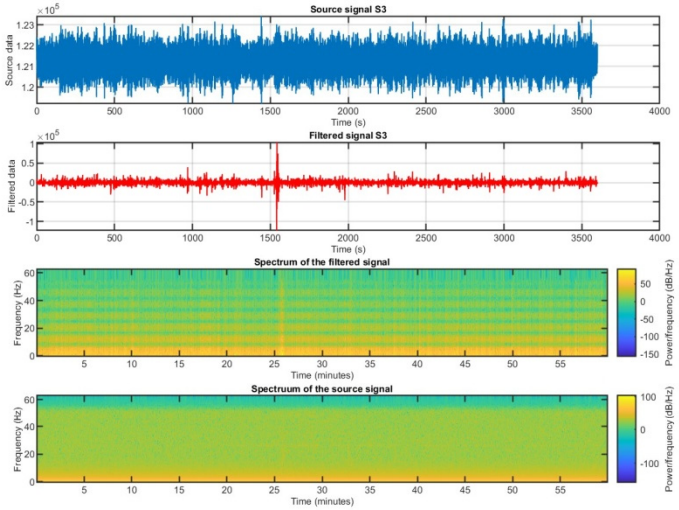
The noisy seismic data was recorded during the powerful earthquake that occurred on December 22, 2018, when the Anak Krakatao volcano produced a devastating tsunami on the Indonesian islands.



CTBT IMS H08S station recorded very noisy signals S1,S2 and S3 of these events. See blue line diagrams. After filtration by statistical filter signal to noise is significantly approved by more then 20 *dB*, see red diagrams.







Researchers recorded very noisy hydroacoustic signals during the flank collapse itself on December 22nd 2018. This is explained by the fact that the collapse was predominantly subaerial (above water), and not underwater, so it did not generate significant hydroacoustic waves.

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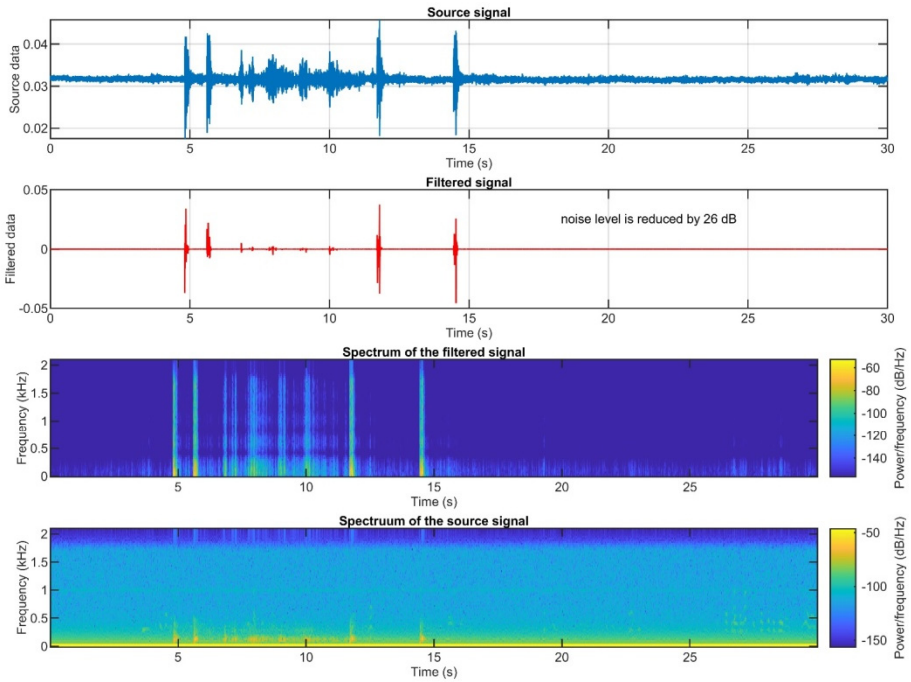
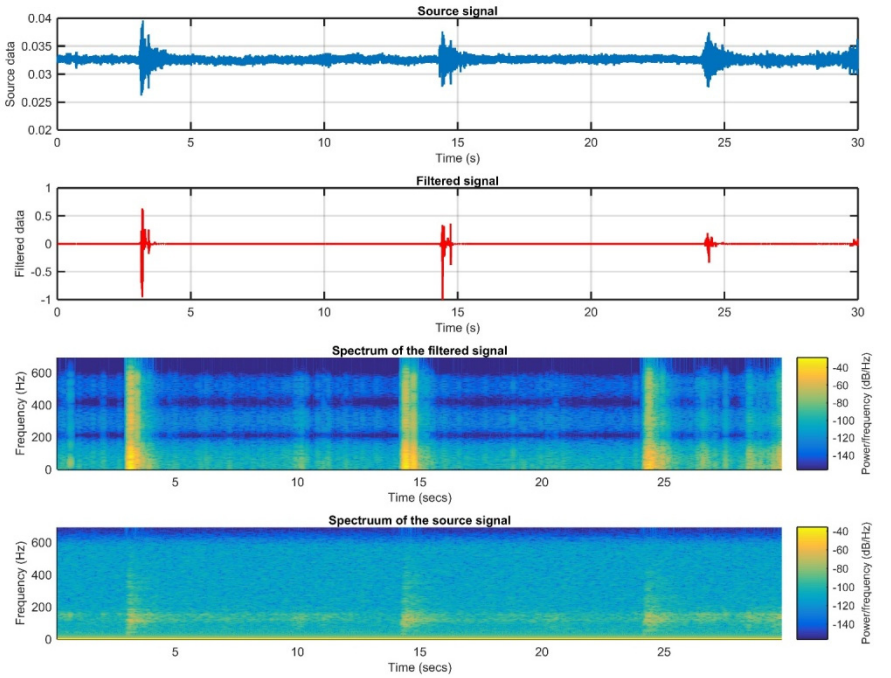
Examples in acoustics: distant explosions in the air

More (four) distant explosions in the air followed by thunderstorms, noise level is reduced by 26 *dB*.



Three distant explosions in the air



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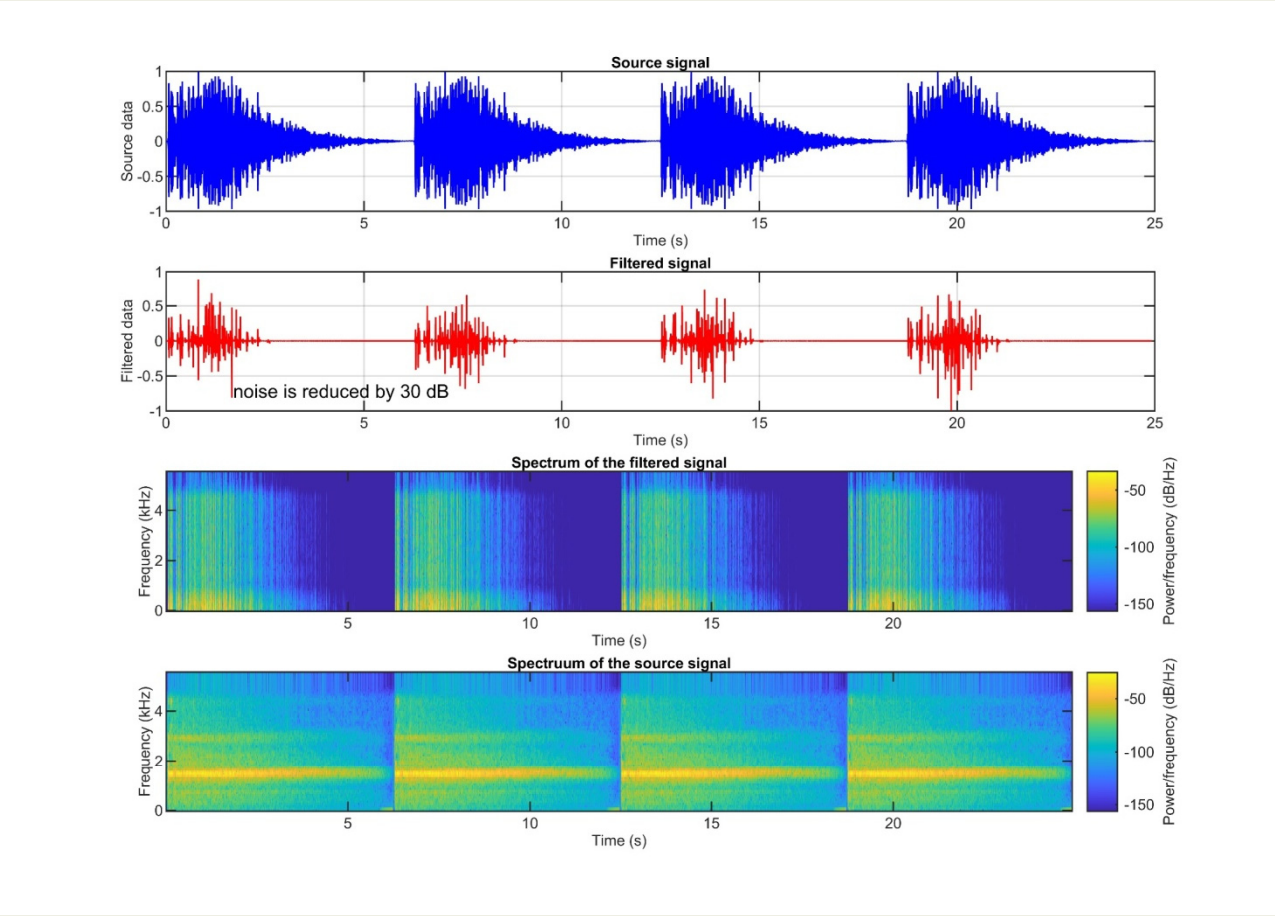
An example in hydroacoustics*): the noise level is reduced by more than 40 *dB*



*) https://pixabay.com/sound-effects/search/atomic%20bomb/ 04.08.2025.
https://soundeffectgenerator.org/sound-effects/nuke-bomb-sound-effect 04.08.2025.
https://voicebot.su/en/category/nuclear-blast/ 04.08. 2025. 12:48

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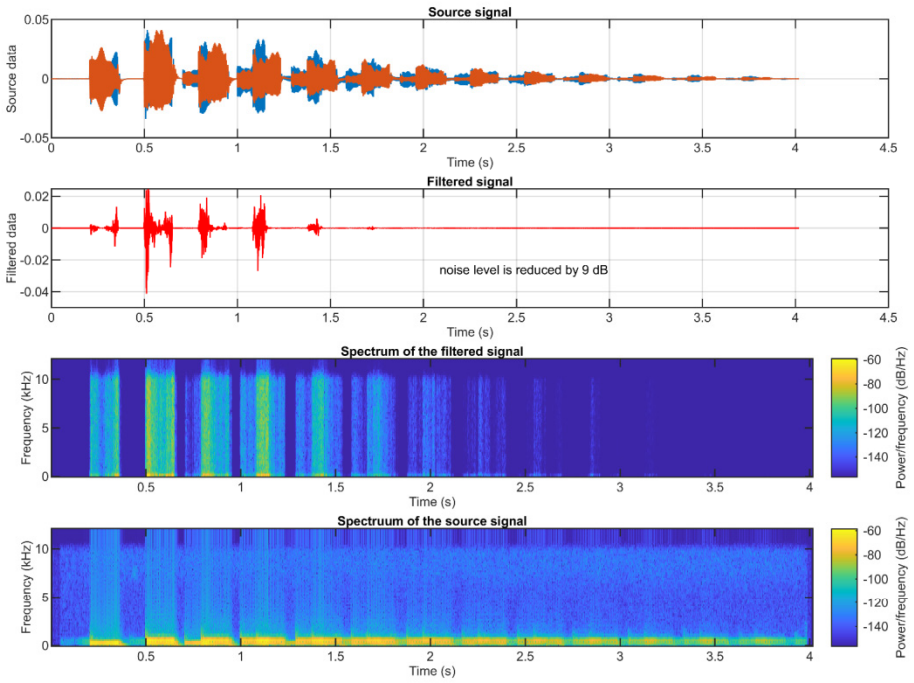
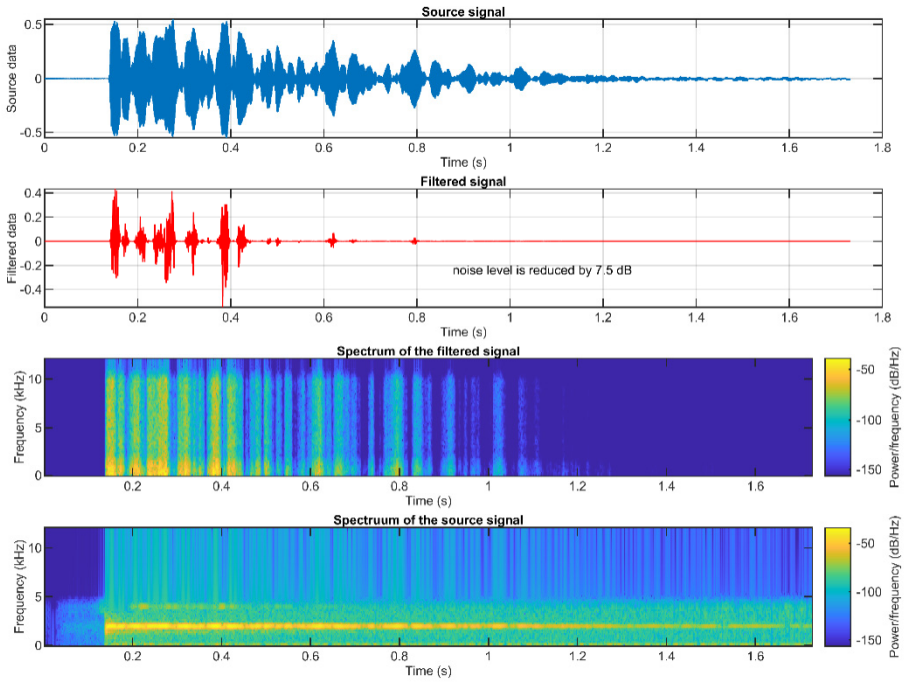
Examples of statistical filter application in radar*)

Noise level is reduced by 9 *dB*



Noise level is reduced by 7.5 *dB*



*) https://pixabay.com/sound-effects/search/atomic%20bomb/ 04.08.2025.
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Examples of filter application in seismics

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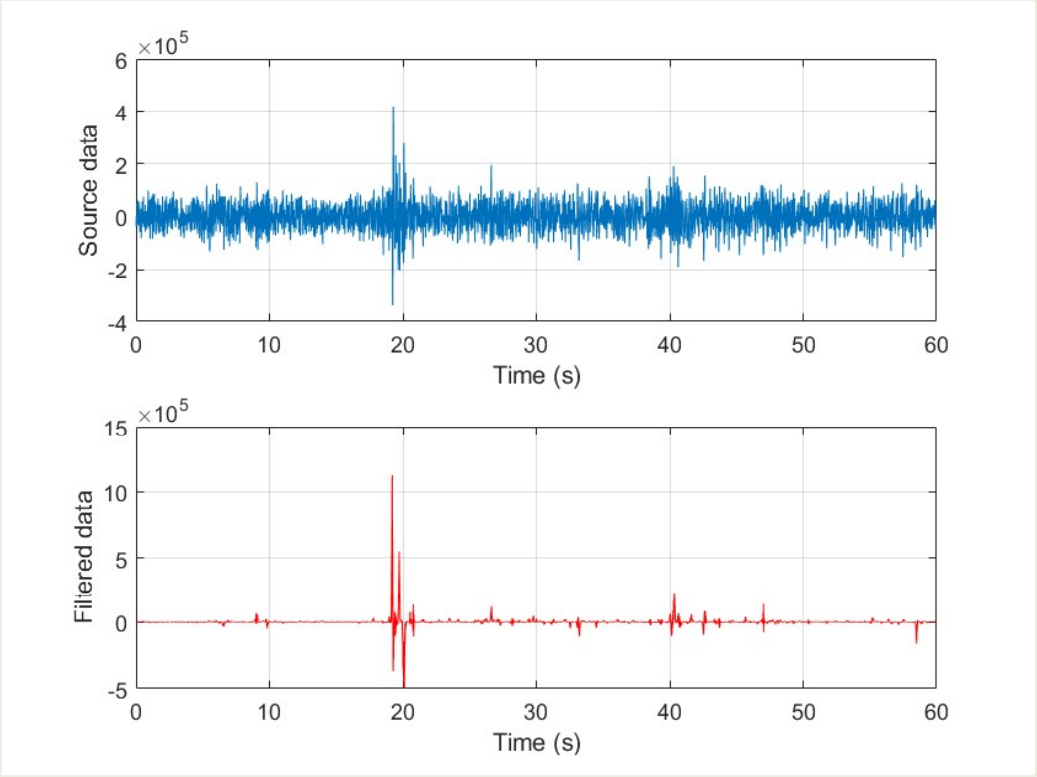
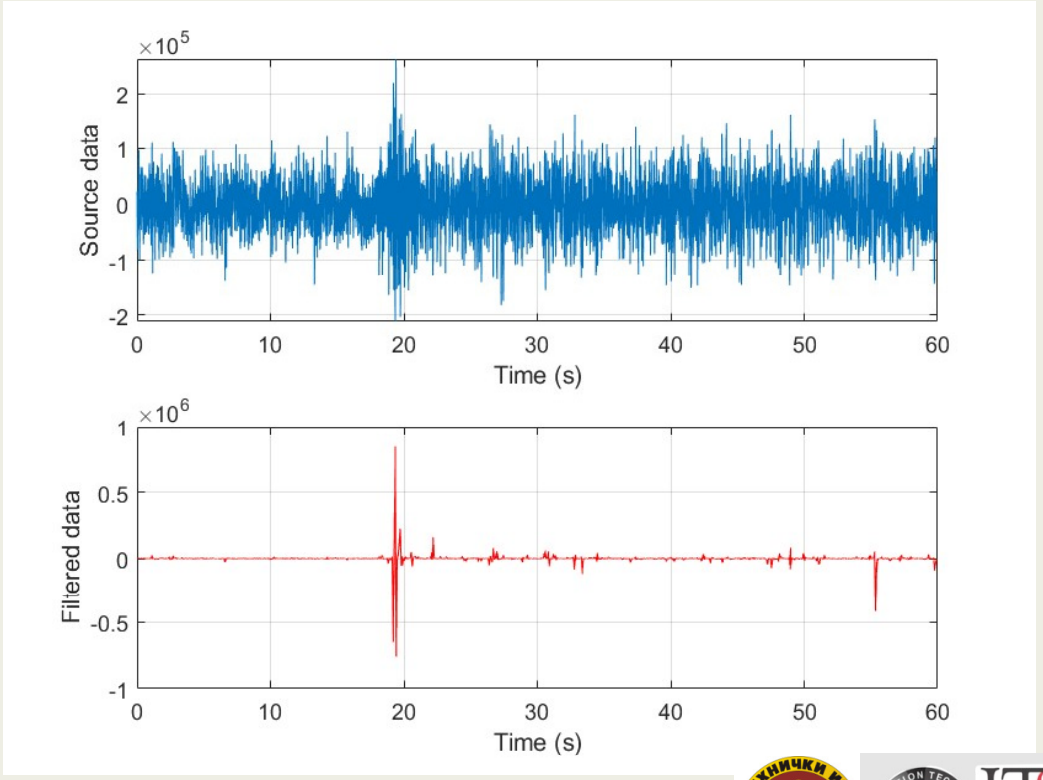


0_SNC_N_20061208_001602*)



*) Data are obtained by courtesy of SONICONA GmbH, Tübingen, Germany