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On-site estimation of the arrival time of an acoustic, seismic or hydroacoustic strongly distorted signals

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INTRODUCTION

In this work we conduct study on-site estimation of the time of arrival (ToA) strongly distorted acoustic, hydroaoustic, seismic and other signals. Wavelet signal analysis and the fourth order cumulant are used in order to better extract useful part of the signal. A so-called statistical filter was developed, which is based on the application of the fourth order cumulant. That enabled to estimate ToA values of the very distorted an noisy signals on-site.

METHODS/DATA

Higher order statistics are very useful in problems where
- non-Gaussianity,
- non-minimum phase,
- coloured noise, or nonlinearities

are important and must be accounted for analysis.

START

RESULTS

- A method of filtering highly distorted and noisy signals based on 4thorder cumulant was developed, i.e. a so-called statistical filter.
- The algorithm for estimation the time of arrival of the wave front (ToA) was successfully applied to signals filtered on this way.

CONCLUSION

- Developed statistical filter
- The filter significantly improves the SNR in highly distorted and noisy signals
- The measurement noise is removed from the signal
- Possible applications in acoustics, hydro-acoustics, seismic, infrasound, radar,..

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Higher – order statistics

Higher-order statistics (spectra) have begun to find wide applicability in many diverse fields, e.g.

- sonar,
- radar,
- plasma physics,
- biomedicine,
- seismic data processing,
- image reconstruction,
- harmonic,
- harmonic retrieval,
- time-delay-estimation,
- adaptive filtering,
- array processing, and
- blind equalization.

The second, third and fourth-order cumulants of zero-mean x(t), which follow from (2) and (3), are

$$C_{2,x}(\tau) = E\{x(t)x(t+\tau)\}$$

$$C_{3,x}(\tau_1, \tau_2) = E\{x(t)x(t+\tau_1)x(t+\tau_2)\}$$

$$C_{4,x}(\tau_1, \tau_2, \tau_3) = E\{x(t), x(t+\tau_1), x(t+\tau_2)x(t+\tau_3)\} - C_{2,x}(\tau_1)C_{2,x}(\tau_2 - \tau_3) - C_{2,x}(\tau_2)C_{2,x}(\tau_3 - \tau_1) - C_{2,x}(\tau_3)C_{2,x}N$$

If a random process is symmetrically distributed, then its third-order cumulant equals zero; hence, for such a process we must use fourth-order cumulants.

- Laplace,
- Uniform,
- Gaussian, and
- Bernoulli – Gaussian

distributions are symmetric [1].

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Flow chart of the statistical filter and ToA estimation

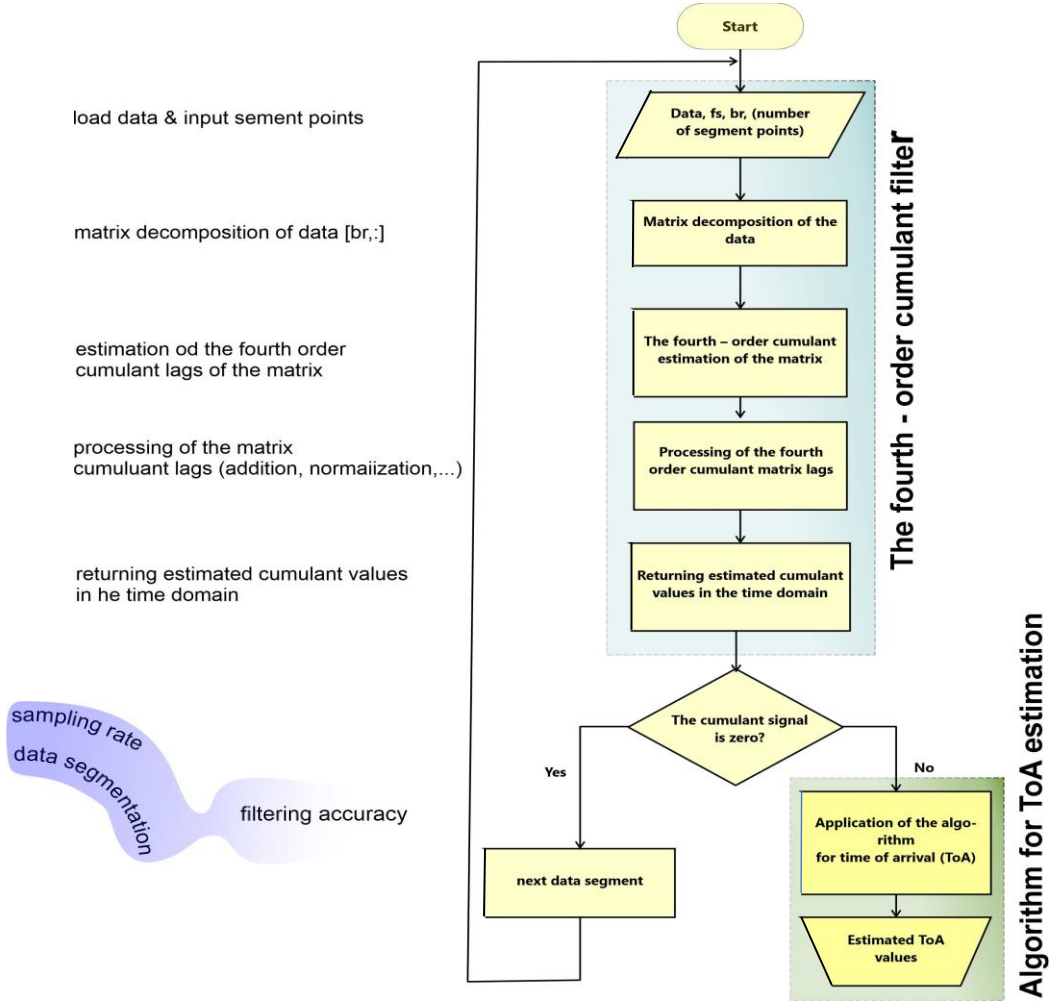

Figure 1. Flow chart of statistical 4th order cumulant filter and algorithm for on-site ToA estimation [2,3].

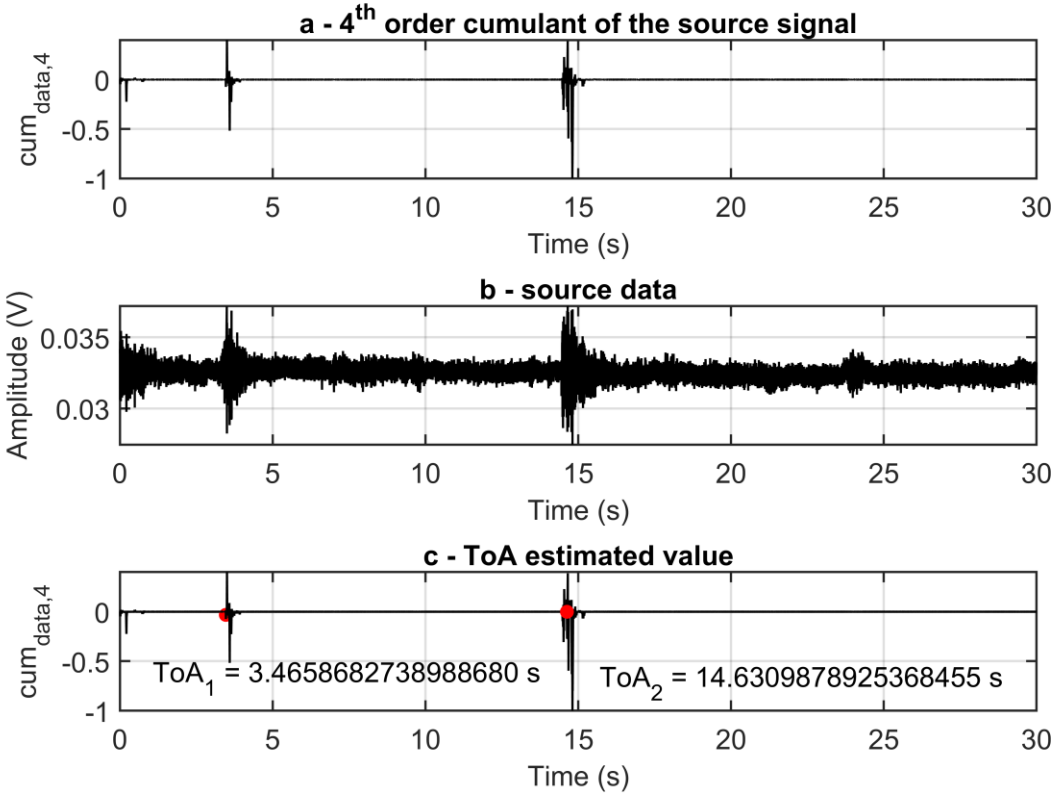

Figure 2. Two gun fire noisy and distorted events. a – filtered data, b – source data, and c – filtered data, and two ToA (Time of Arrival) estimates.

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Statistical and wavelent filtration of the noisy and distorted signals

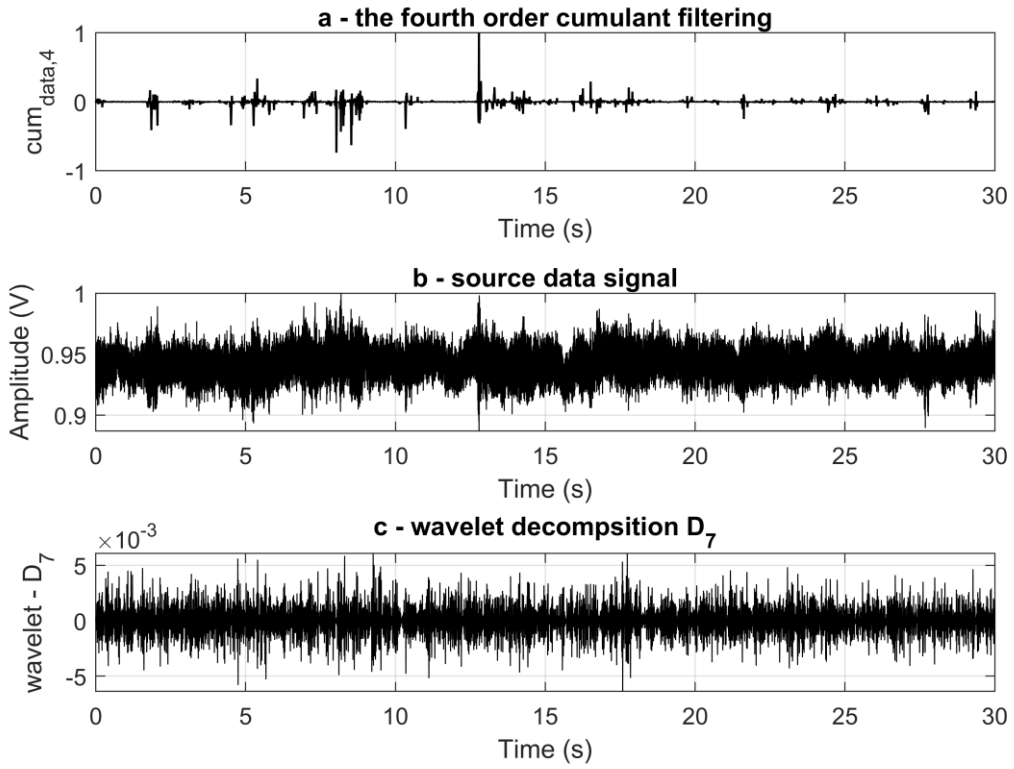

Figure 3. Signal filtering. a – Filtered signal using a statistical 4th order cumulant filter (or just statistical filter), b –Source data from seismic sensor [4], and c -wavelet decomposition of the signal (Daubechies wavelet coefficient of 7th order [5] (D_7).

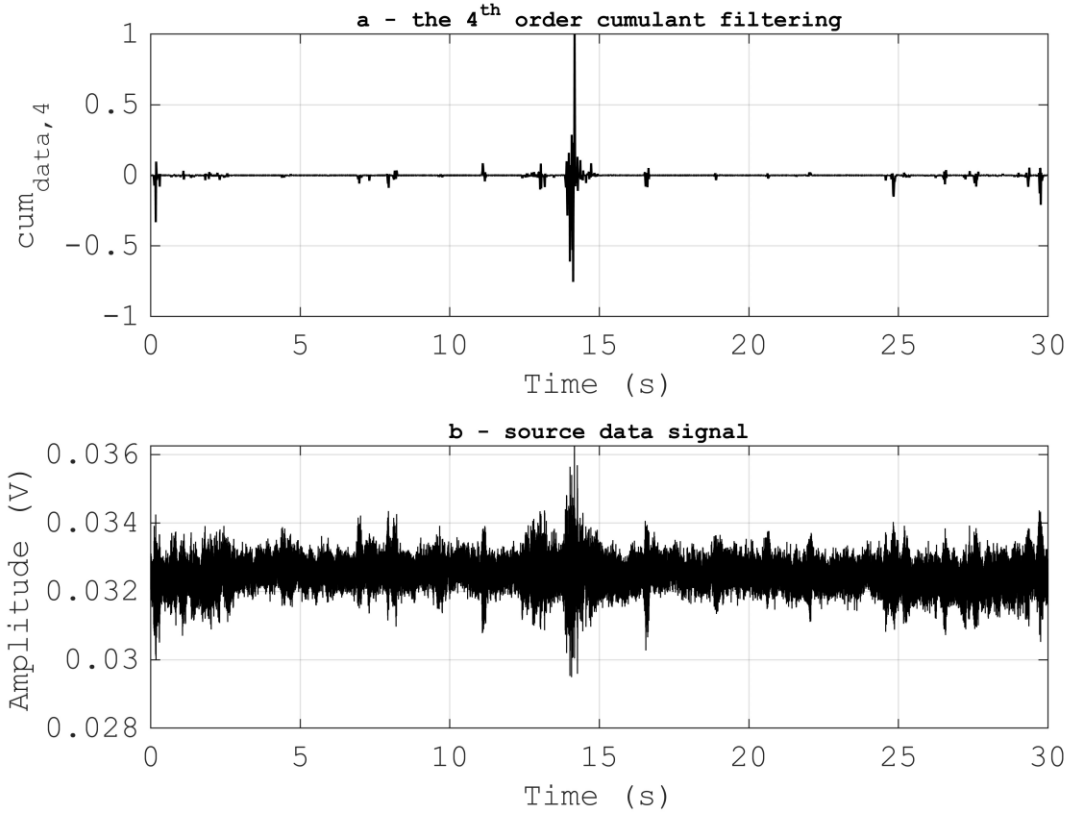

Figure 4. By applying a statistical filter, the noise and distortion of the acoustical signal is significantly removed, see figure (a), and figure (b) show source data.

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Noise and distortion removal, and ToA estimation on-site

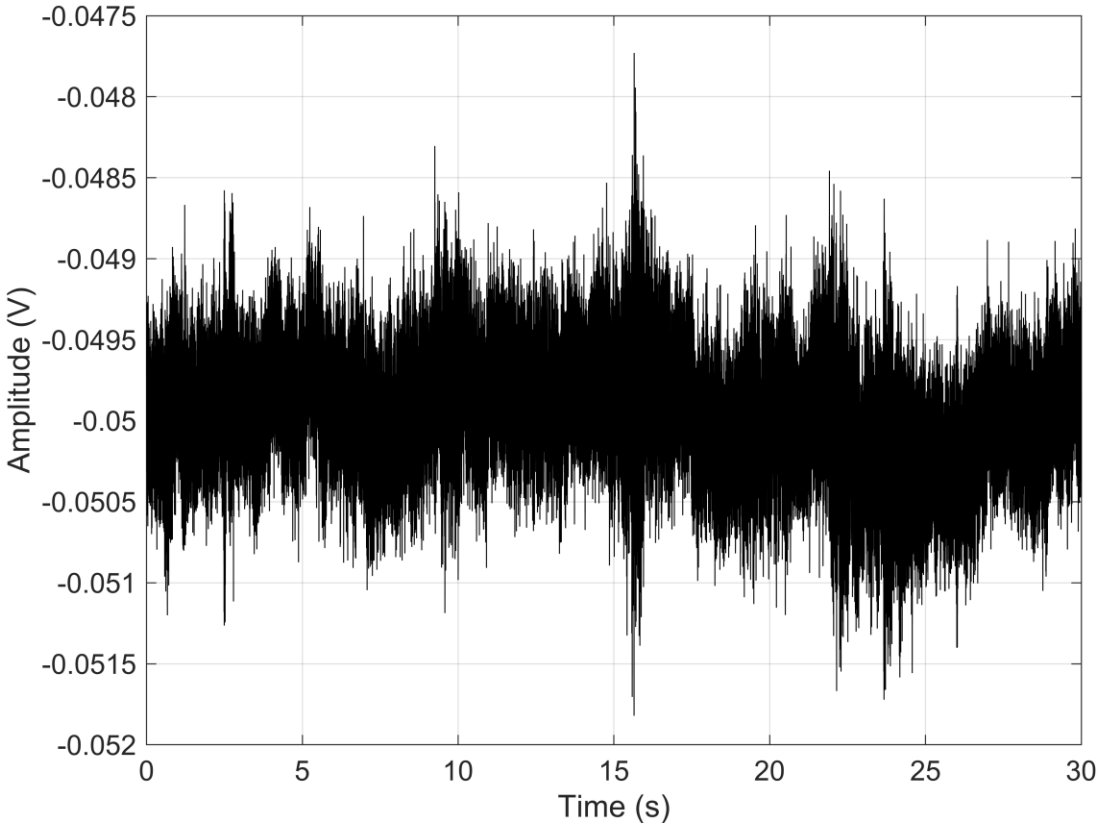

Figure 5a. Case of very distorted and noisy acoustic signal which originate from gun fire.

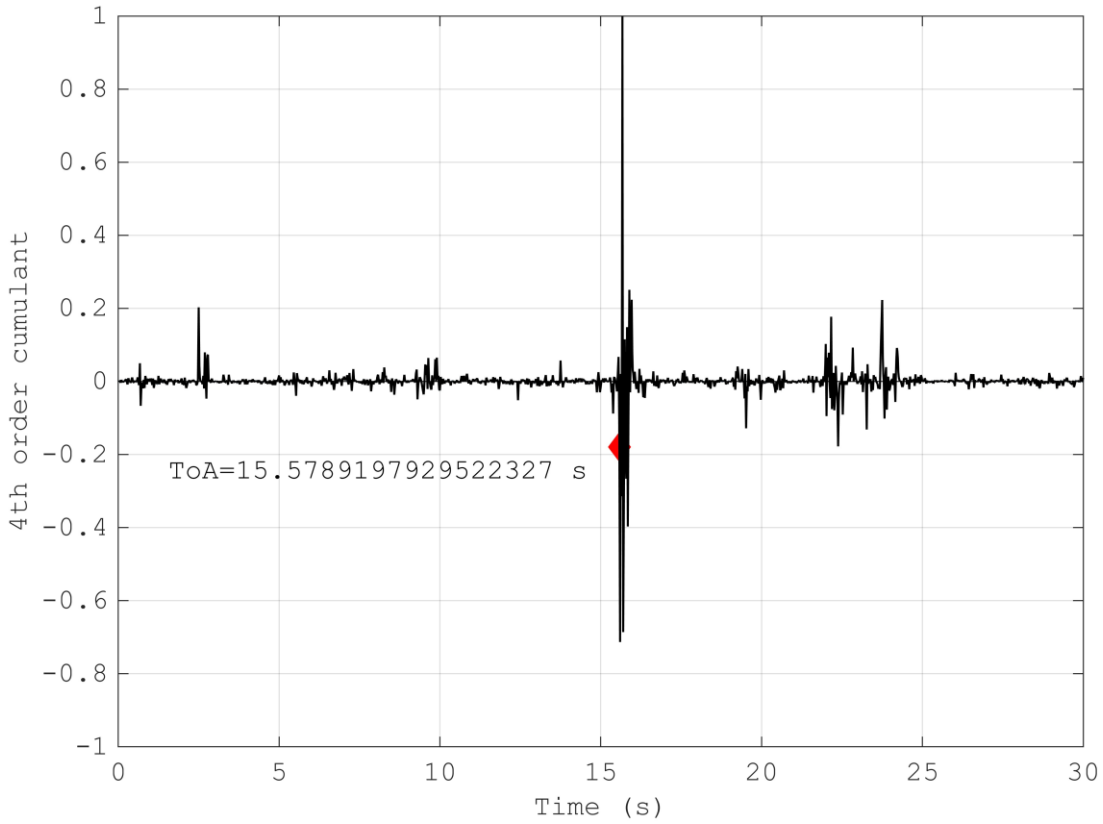

Figure 5b.The signal from Fig. 5a after filtering with statistical filter. In addition, algorithm for on-site estimation ToA is applied and ToA value is successfully estimated [3].

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Conclusions

- A method of filtering very distorted and noisy signals, based on 4th order cumulant, is developed, i.e. a so-called statistical filter.
- The algorithm for estimation the time of arrival (ToA) of the wave front is successfully applied to the signals filtered in this way.
- The statistical filter significantly improves the SNR (Signal to Noise Ratio) of very distorted and noisy signals.
- The measurement noise is removed from the signal.
- Possible applications in acoustics, hydroacoustics, infrasound, seismic, radar, and other areas.
- Filtrating and ToA estimate is possible to do on-site, and it is thus possible to significantly reduce the load on the data transmission network by sending only estimated ToA values, and/or parts of data with useful content.

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