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SIGNAL VALIDATION IN MEASUREMENTS IN UNDERWATER ENVIRONMENT

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Abstract − Satisfying requirements of credibility of measurements in underwater environment is possible through validation of measuring signals, registered under measurement experiments. This paper deals with signals registered for ambient noise characteristics calculation.

Procedure of signal validation based on wavelet transform is described and parameter characterizing a quality of registered signals is proposed.

Keywords: signal validation, wavelet

1. INTRODUCTION

Validation is the process of verifying or demonstrating correctness. When dealing with measurements, validation requires a demonstration that the collected data are useful and the results of measurements are replicable. It is widely recognized and usually assumed in measurement experiments that series of observations are obtained under repeatable conditions in the measurement environment. It implies that *influence quantities* [4], which can affect the measurement results (measurands), are approximately constant under measurement experiment.

Satisfying requirements of credibility of measurements in underwater environment is difficult because of nature of measurement environment.

This paper deals with validation of signals registered for ambient noise characteristics calculation.

It can be said that the ambient noise is the residual noise background in the absence of any individual identifiable sources or that ambient noise indicates that wind-generated noise is predominant source of the total ambient noise is natural noise environment at a measurement site [2].

The measurement of the ambient noises can be considered as a procedure of calculations of underwater noise characteristics (RMS level, power density spectrum level, probability function, etc.) from a set of measuring signals.

The nature of the measurement environment of the underwater noises introduces some troubles in the approach to reproducibility of the measuring signals. Briefly, it may be characterized as follows:

- activities of many sources of noise at the same time,
- varying propagation of the acoustic waves in the underwater environment,
- random influence of the surroundings on the measurement environment (especially in the coastal zone),
- short time disturbances influenced on sensors.

In the subject literature [2,5], the characteristics of ambient noises have been described as a function of the sea state (expressed in Beaufort scale) or wind force. They have been treated simultaneously as the determinants of the conditions of the measurement experiments in underwater environment. However, it is necessary to point out that both mentioned parameters determine only the influences of natural forces on the sea surface and they do not mirror the contribution of another noise sources in acoustic field. Moreover, the Beaufort scale is very subjective.

Having in mind the described conditions of measurement experiments in underwater environment, the essential problem in the ambient noise characteristics measurement is to establish an ensemble of the valid signals, which are representative for the observed phenomenon. This problem is extremely crucial in the coastal zone, where, additionally, a man-made contribution to the ambient noise level is significant. At conclusion, the results of the ambient noise measurement might be different for the same sea states, therefore, they can be difficult to compare and generalize.

One of the popular ways of validation of hydroacoustic signals is their review using the perception methods, i.e. auditioning and depicting. The both of the methods are subjective and time consuming.

To devise an objective procedure of validation of signals registered for ambient noise characteristics calculation it is advisable to consider two stages. The first one is the analysis of homogeneity of the single signal according to any criterion. The second one is the cluster analysis of collected signals for establish representative sets for fixed sea state, customarily defined in the Beaufort scale.

This paper deals with the first stage and the procedure of signal validation based on wavelet analysis of measuring signals has been proposed.

2. PROBLEM DEFINITION

The procedure of validation of the single signal is dealing with extraction of the segment of the signal which satisfies two conditions. The first one, the extracted segment is homogeneous and, secondly, its average energy is minimal. Additionally, if there are more segments in the signal which satisfy above conditions, the result of validation is the maximum length segment.

Formally, the procedure of signal segmentation can be described as follow.

Let

$$X = \{\{x^{(1)}\},\{x^{(2)}\},...,\{x^{(K)}\}\} \quad (1)$$

denote the set of measuring signals registered for fixed sea state and let

$$\{x^{(k)}\} = \{x_1^{(k)}, x_2^{(k)},...,x_N^{(k)}\} \quad (2)$$

to be a sequence of samples of measuring signal $x^{(k)}$. Under above assumptions the segments of $\{x^{(k)}\}$, in which the signal is homogenous, should be extracted.
Formally, the segmentation may be defined as follows [1].

Definition
A segmentation $\Sigma = (\Pi, L)$ of $\{x^{(k)}\}$ consists of a partition $\Pi = \{S_1, S_2,...,S_m\}$ of $\mathrm{Dom}(\{x^{(k)}\})$ into regions and a logical predicate L that applies to subset of $\mathrm{Dom}(\{x^{(k)}\})$.

The predicate L identifies each segment S_i as a maximal region, where $\{x^{(k)}\}$ is homogenous. Then $\Sigma = (\Pi, L)$ is a segmentation of the signal into meaningful and distorted partitions and some mathematical operation on the signal defines the logical predicate L.

In the boundary case the result of validation can be a full length signal, what is equivalent to the case of registration of signal without influences of distortions on measuring environment or when the level of distortions is constant. Respectively, the segment of the maximum length is that part of the full length signal, in which the influence of distortions is the smallest or this part of the signal is free from distortions.

3. PROCEDURE OF SEGMENTATION

As it was pointed out in the previous section, the distinctive of measuring processes of ambient noises signals are non controlled activities of different noise sources in the measurement environment. The manifestation of these activities are the local changes of energy of signals. Therefore, for extraction of meaningful and distorted partitions, the analysis of energy distribution in signal should be done. Proposed method of the analysis of energy distribution is based on multilevel wavelet transformation with use Malvar wavelet. The choice of Malvar wavelet is justified by its properties which can be shortly described as follows:

- the Malvar wavelets form an orthonormal basis of $L^2(\Re)$, which is necessary for the computation of the statistics of the probability low followed by the coefficients,
- they are defined with cosine functions and they are well adapted to oscillatory nature of the signals we want to analyze,
- their fast computation time makes them advantageous from practical point of view.

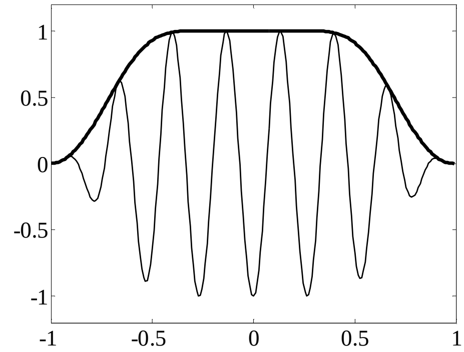

Fig. 1. Malvar wavelet on [0,1].

Graphical interpretation of the 4-level wavelet decomposition with Malvar wavelet is shown on Figure 2. For homogeneity testing, energy of Malvar coefficients is calculated and compared for adjacent records on the each levels of wavelet decomposition.

C_0															
C_{11}								C_{12}							
C_{21}				C_{22}				C_{23}				C_{24}			
C_{31}		C_{32}		C_{33}		C_{34}		C_{35}		C_{36}		C_{37}		C_{38}	
C_{41}	C_{42}	C_{43}	C_{44}	C_{45}	C_{46}	C_{47}	C_{48}	C_{49}	C_{4A}	C_{4B}	C_{4C}	C_{4D}	C_{4E}	C_{4F}	C_{4G}

Fig. 2. 4-level wavelet decomposition of signal with Malvar wavelet.

For the description of the proposed procedure of the single signal segmentation lets use the following notation. Let E denote energy of the set C of the Malvar coefficients. Next, let E_0 denote energy of the set C_0 on the zero level signal decomposition, E_{11}, E_{12} energies of the sets C_{11}, C_{12} on the first level signal decomposition, E_{21}, E_{22}, E_{23}, E_{24} energies of the sets C_{21}, C_{22}, C_{23}, C_{24} on the second level signal decomposition and so on. Let subscript N denote the number of records of decomposed signal and n to be n-th record of the analysed signal. Under above assumptions, procedure of segmentation is as follows:

phase I:

- divide the signal into N records of the same length,
- carry out four level wavelet transformation,
- set up the table of the set C of the Malvar coefficients,
- calculate the energy E_0^n for each of the records,
- calculate $E_{0max}^n = max[E_0^1, E_0^2,...,E_0^N]$,
- calculate threshold value of energy $E_{0th} = E_{0max}^n * \varepsilon$ where $\varepsilon = (0,1)$ is a coefficient,

phase II:

- for n=1 to N check condition

$$\left|E_0^{n+1} - E_0^n\right| \le E_{0th} \quad (3)$$

- for each pair of records satisfying the condition (3), test the *n-th* record for its internal homogeneity using the formula

$$\left|E_k^{l+1} - E_k^l\right| \le E_{kth} \quad (4)$$

where l denotes the number of the subrecord on the k-th level of Malvar decomposition and $E_{kth} = E_{0th} / 2^k$ for k=1,2,3.

phase III:

- all adjacent records satisfying the conditions (3) and (4) join into S_i segments,
- calculate average energy for each S_i segment,
- choose the segment of maximum length for which the average energy is minimal.

All of the records satisfying the conditions (3) and (4) are homogenous in an energy distribution sense on the taken level threshold of energy difference. The choice of ε value is arbitral but the smaller the value of ε, the more rigorous requirements on homogeneity of analysed signal are.

The selection of the segment of the maximum length for which the average energy is minimal is equivalent to the case when the influence of disturbances on the measurement environment is minimal or when the level of distortions is constant under signal registration. The segment which is the result of the validation procedure is representative for analysed measuring signal. Its final qualification to the set of signals, which are representative for fixed sea state, takes place under the cluster analysis.

4. QUALITY PARAMETR

Having in mind that the result of the segmentation is a partition of measuring signal consisted of homogenous segments of signals, the parameter characterizing the quality of signal may be defined as follows:

$$\widehat{F} = \frac{L_{max}}{L} \quad , \quad (3)$$

where:

L_{max} - the length of of homogenous segment of the maximum length,

L - the length of analysed signal.

It is assigned that the length of registered signals under measuring process is the same.

There are several motivations behind the use of (3) as a parameter expressing the quality of the measuring signals:

1. The bigger value of $\widehat{F}$ is, the better quality of the measuring signal.
2. Small values of $\widehat{F}$ indicate a weak quality of the measuring signal.
3. For the fixed sea state, analysis of $\widehat{F}$ enables a comparison between the quality of registered signals and a selection of those for which the length of homogenous segments is maximal.

Modified parameter $\widehat{F}$ may be used for estimation of measurements credibility in underwater environment [6].

5. RESULTS

The proposed procedure of signal validation has been implemented in MATLAB. Using GUI (Graphical User Interface), the user can set up the following parameters:

- the name of the analysed signal,
- length of record for wavelet decomposition,
- the number of levels of decomposition of wavelet transformation,
- value of the coefficient ε.

The signal should be written in ascii code. The length of the record and the number of levels of the decomposition depends on desired accuracy of the analysis of the measuring signal. The default values of those parameters are 4096 and 4 respectively. The value of the coefficient ε ranges from $\varepsilon = (0,1)$.

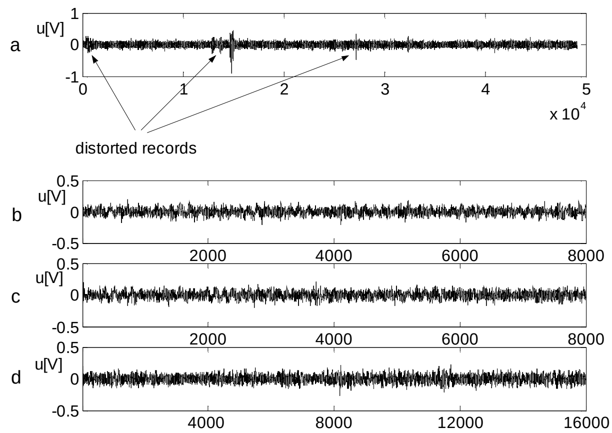

Fig. 3. Results of signal analysis: a) original signal, b-d) homogenous records.

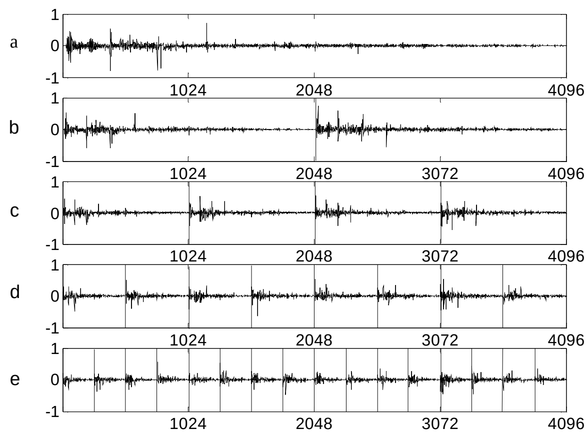

Fig. 4. 4-level wavelet decomposition of record of signal with Malvar wavelet.

The result of signal analysis is depicted in the window which consists of the following data:

- the numbers of homogenous segments,

– the range of homogenous segments in analysed signal,
– the average energy of segments,
– the value of quality parameter $\widehat{F}$.

As an example of application of the described procedure of signal validation there are presented the results of analysis of the measuring signal which was registered in underwater environment. The signal was registered in a coastal zone at sea state equal to 1-2 B. The sample frequency was equal to 5.12 kHz.

The distortions pointed in the Figure 3a (causing the local non stationarities) are a manifestation of unknown activity and non recognized sources in the measuring process.

The procedure of signal validation was done for the length of record of wavelet decomposition equal to 4096 and 4-level Malvar transformation. The example of 4-level wavelet decomposition of record of signal with Malvar wavelet is shown in the Figure 4.

The results of signal analysis are placed in Table 1. There are three homogenous segments for the value of the coefficient ε equal to 0.05 (Figures 3b-d).

Table 1. Results of signal validation.

	Range		Length	Average energy [V^2]	$\widehat{F}$
Segment1	4097	12288	8192	0.0026	0.18
Segment2	16385	24576	8192	0.0027	0.18
Segment3	32769	49152	16384	0.0026	0.36

The Segment3 has the biggest length equal to 16384 samples. Its average energy is 0.0026 [V^2] and is smaller than the average energy of the analysed signal which is equal to 0.0032 [V^2]. It means that the Segment3 is the final result of validation of the analysed signal. This result is consistent with the expectations because one can state that influences of non natural sources on the selected parts of signal are minimal.

Analysing the values of the $\widehat{F}$ parameter in Table 1 it is easy to deduce that the Segment3 represents about 40% and all of the homogenous segments represent about 70 % of the length of the measuring signal.

6. CONCLUSIONS

In this paper the problem of validation of signals registered in underwater environment has been taken up. The need of validation of hydroacoustic signals comes from the specificity of measuring experiments in underwater environment where activity of unknown and non recognized acoustic sources can cause the local non stationarities in registered signals. In the introduction of this paper, the environmental conditions of recordings of hydroacoustic signals has been widely described.

As an alternative to perceptive methods commonly used in hydroacoustic, an objective method of hydroacoustic signals validation has been discussed. The method deals with research of homogeneity of measuring signals and enables extraction of valid segments from analysed signal.

The proposed procedure is based on energy analysis in the records of signal with the use of Malvar wavelet transformation.

The parameter characterizing the quality of measuring signals has been proposed.

The criteria for the homogeneity of records testing can be various but they should ensure sufficient distinction of ambient noise signals.

More sophisticated procedures are the subject of the future researches of the author. The promising results are given by the analysis of statistical distribution of signal values where the kernel estimators can be applied to signal segmentation.

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REFERENCES

[1] R. L. Allen, D. W. Mills, *Signal analysis*, Wiley&Sons, 2004.
[2] L. Bjorno, “Sources of ambient noise in shallow waters”, *XLIV Open Symposium of Acoustics*, p. 35-50, Jastrzebia Góra, Poland, Sept. 1997.
[3] I. Daubechies, *Ten lectures on wavelets*, Society For Industrial & Applied Mathematics,U.S, 1992.
[4] *Guide to the expression of uncertainty in measurement*, Int. Organisation for Standardisation, 1993.
[5] W. Kiciński: “A statistical model for sea ambient noise classification.” *Oceanologia* vol. 39, no 3, pp. 227-235, July 1997.
[6] W. Kicinski, “Processing of measuring signals for monitoring of transients in underwater environment”, *XVII IMEKO World Congress*, pp. 2098-2001, Dubrovnik, Croatia, June 2003.
[7] S. Mallat, *A wavelet tour of signal processing*, Academic Press, New York, 1999.
[8] J. Nasi, A. Sorsa, *On-line measurement validation through confidence level based optimal estimation of a process variable*, Report A no 25, University of Oulu, Finland, 2004.