DETERMINATION OF P PHASE ARRIVAL IN LOW-AMPLITUDE SEISMIC SIGNALS FROM COAL-MINES WITH WAVELETS

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ABSTRACT

The aim of this article is to present an application of wavelet transform for P phase arrival detection in seismic signals from Polish coal-mines. The main idea is to use this methods to low amplitude, therefor noisy seismic signals. We can use the fact that the begining of P wave of the seismic signal can appear in the wavelet coefficiens across several scales. In this article the method is presented that locates these arrivals in one-component seismic signals.

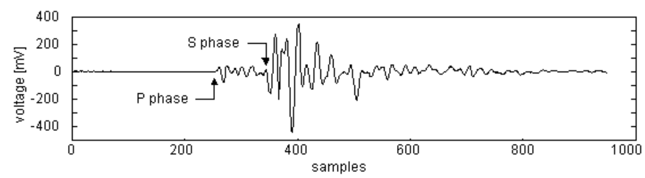

Figure 1: An example of one-component seismogram registered in coal-mine tremor station, with P and S phase arrivals.

1 INTRODUCTION

Coal-mining leads to arising the varied of dangers. One of the most important is seismic events due to stress. This events – mainly rock mass vibration and tremors – can produce rock bursts. The prediction of occurrence of mining rock bursts is indisputable the most important for the safety of mining and protection of human lives. Therefore the important is to record these events and localize them. Various apparatus works at mining tremor stations to register this events. Some of them, working in Polish coal-mines, are presented in [1].

A seismic signal, which contain an information about seismic event, consist of several different phases (waves), amongst them significant are the P phase and S phase. An example of seismic signal is depicted in Figure 1. These phases are common used in seismic event localization. To do this we need the P and S phases arrival times. Accurate time arrival determination of these two phases is important in exact localization. In coal-mines are registered only one-component seismograms in practice (typically from 8 up to 16 channels), therefore mainly the P phase times arrival are used in localization method.

Traditionally the localization has been done by analyst, who base on P phase time arrivals determined by an automatic picking algorithm. There are many methods of P phase detection, based on moving averaging of signal envelope or based on short-term-average (STA) to long-term-average (LTA) [2, 3, 4] In some cases algorithm applied in tremor station cannot recognize P phase correctly. This is when the signal has low amplitude, and therefore low signal to noise ratio. The examples of such signals are presented at Figure 2. Because analyst isn't able to mark the P phase, these signals are rejected.

The aim of this paper is to propose another method of P phase arrival detection based on wavelet analysis. These methods was previously used in P phase and S phase detection, but in a three-component seismic signals [5, 6]. Using discrete wavelet transform (DWT) it is possible to build effective method of P phase time arrival detection, which for weak seismic signals is more robust then currently used. The appropriate methods was implemented in computer program and tested in real seismic signals.

2 PROPOSED APPROACH

The wavelet transform is a very useful tool in the analysis of nonstationary signals such as the seismic signal. The theory and methods of wavelet analysis is widely presented in books [7, 8, 9]. We use discret version of wavelet analysis, which uses the concept of multiresolution analysis (MRA) introduced by Mallat [10].

With the MRA we can recursively decompose signal into a sum of its details and approximation at different levels of resolution, as shown in Figure 3. The details represent high-frequency components, while the approximations represent the low-frequency components of the signal.

The decomposition algorithm is fully recursive. At each stage of MRA signal is passed through a high-pass

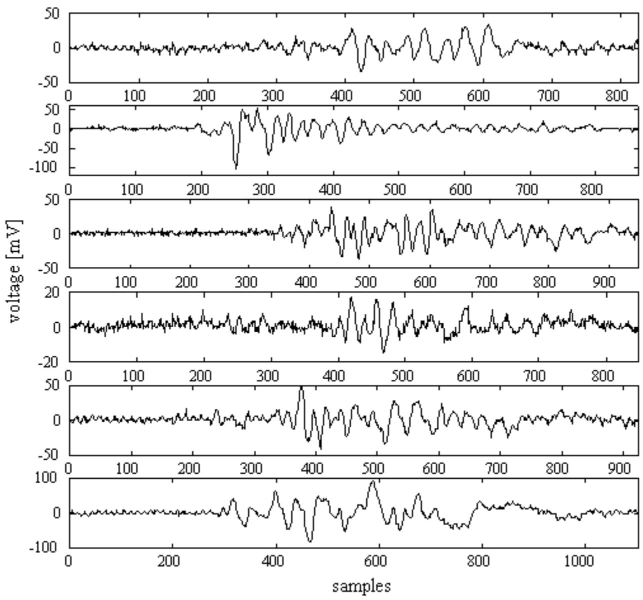

Figure 2: Seismic signals from *Wujek* coal-mine (Poland, Upper Silesia Coal Basin), with ambiguous P phase arrival.

filter (called scaling filter), denoted as $\boldsymbol{G}$, and low-pass filter (called wavelet filter), denoted as $\boldsymbol{H}$. These are quadrature mirror filters, that satisfy the ortogonality conditions

$$\boldsymbol{HG}^*{=}\boldsymbol{GH}^*{=}\mathbf{0} \text{ and } \boldsymbol{H}^*\boldsymbol{H}{+}\boldsymbol{G}^*\boldsymbol{G}{=}\mathbf{I}$$

where $\mathbf{I}$ is the identity operator. Filters $\boldsymbol{H}$ and $\boldsymbol{G}$ are decomposition filters, while $\boldsymbol{H}^*$ and $\boldsymbol{G}^*$ are reconstruction filters. The values of these filters coefficients depend on particular wavelet. The process of decomposition of signal and reconstruction of approximations and details is presented in Figure 4.

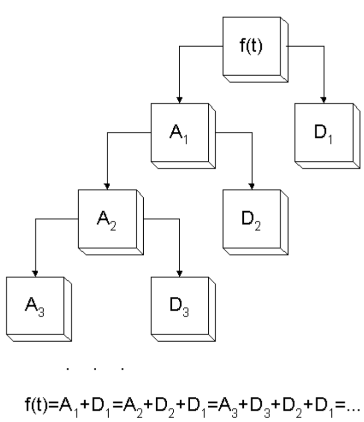

Figure 3: Decomposition tree of signal $f(t)$. D_i and A_i are the details and approximations at level i.

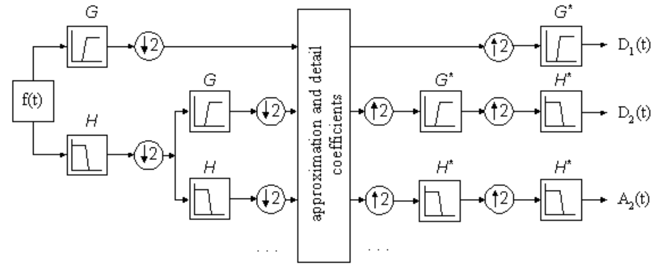

Figure 4: The process of decomposition and reconstruction of approximations $A_i(t)$ and details $D_i(t)$. Symbols $\downarrow 2$ and $\uparrow 2$ represent dyadic down-sampling and up-sampling.

The abrupt changes in signal are clearly visible in details, therefore details were used for detection of P phase arrival. Haar wavelet was used to detect the beginning of P phase in seismic signal due to its good time localization.

3 RESULTS

Applying MRA to low amplitude, therefore noisy seismic signal, we can notice that details at first few levels of decomposition contain much noise, but at subsequent levels we can notice the jump of details at the moment of P phase arrival. By rejecting details at first few levels of decomposition and multiplying the absolute values of details at subsequent levels, we can gain the effect of details jump. This is shown in Figure 5. Some of the results for normally acquired (not low-amplitude) signals and comparison to standard literature STA/LTA algorithm was presented in [11]. Better results can be archived with preliminary denosing.

3.1 Denoising

Wavelet based methods was also applied for denoising. This approach to signal denoising seems to be better here than traditionally, low-pass Butterworth filtering. Because we do the apmlitude denoising instead of frequency denoising, we can also suppress low frequency noise.

The raw signal was denoised by thresholding the details coefficeints. The simplest method is hard theresholding. If the original details coefficients are $d(t)$, the new value of $\hat{d}(t)$ from hard thresholding are

$$\hat{d}(t) = \begin{cases} d(t) & \text{if } |d(t)| > ts \\ 0 & \text{if } |d(t)| \leq ts \end{cases} \tag{1}$$

where ts is threshold.

Another method of thresholding is soft thresholding, according to formula

$$\hat{d}(t) = \begin{cases} sign(d(t))(|d(t)| - ts) & \text{if } |d(t)| > ts \\ 0 & \text{if } |d(t)| \leq ts \end{cases} \tag{2}$$

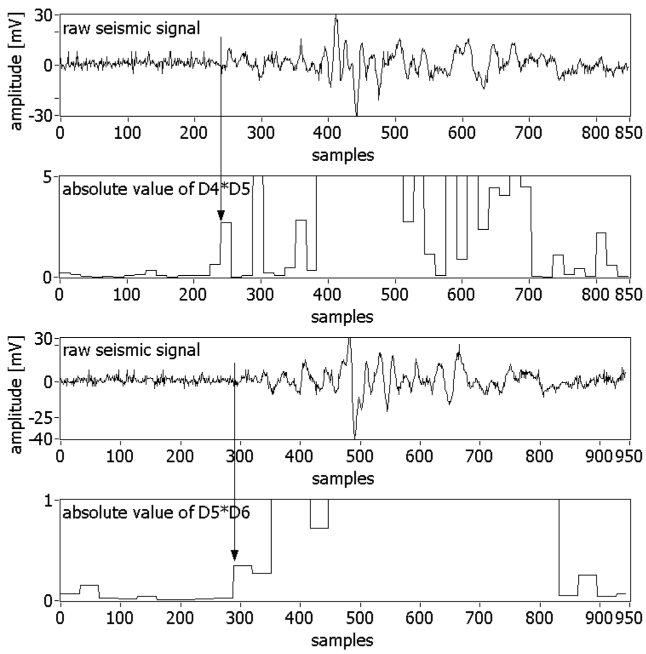

Figure 5: Results of P phase arrival detection in seismic signals before noise suppression. Signal jump detection was done by multiplying absolute values of selected details

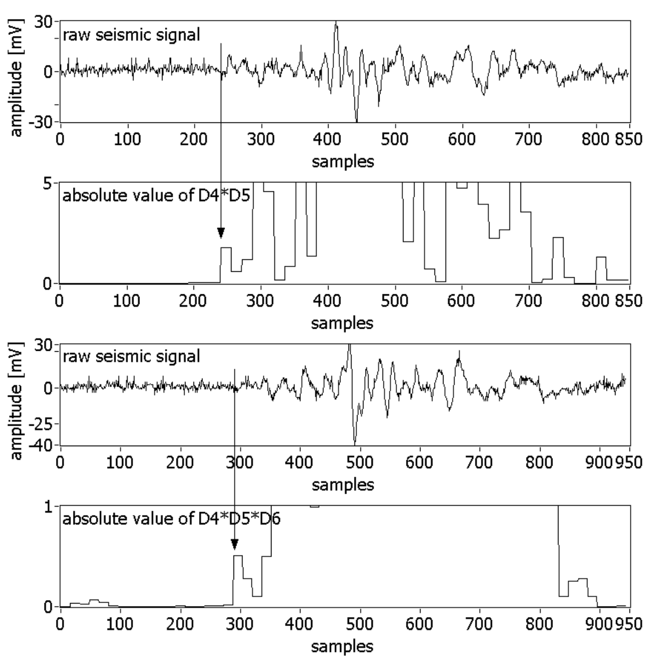

Figure 6: Results of P phase arrival detection in seismic signal after noise suppression. Signal jump detection was done by multiplying absolute values of selected details.

Hard or soft thresholded details coefficiens are then used in signal reconstruction instead of the original one. The threshold ts is estimated most ofen as

$$ts = \sigma\sqrt{2\ln(n)} \tag{3}$$

where n is the length of thresholded coefficiens and σ characterizes the noise level. This and the other methods of threshold selection are described in works of Donoho and Johnstone [12, 13]. If we assume, that noise is essentially in the finest (first) scale, we can calculate its estimate as the median absolute deviation of detail coefficients from this scale

$$\sigma = median(|\mathbf{d_1}|)/0.6745 \tag{4}$$

If the noise is nonwhite, it should be estimated separately for each level.

The wavelet used to denoising the seismic signal was the Daubechies wavelet, with vanishing moment from 4 to 12. The decomposition level for denoising was not higer than 5. Then the Haar wavelet was used to P phase detection in denoised signal. An example of P phase arrival detection in denoised signals is shown in Figure 6.

The methods described in this article were implemented in computer program (see Figure 7). This program is used by the author for seismic signal denoising and P phase detection as well as it is preparing to be tested in coal-mine tremor station, as an aided program for P phase detection in low amplitude seismic signals. Currently the three, well known orthogonal wavelets were implemented in the computer program: daubechies, coiflets and symlets.

4 CONCLUSION

The discrete wavelet approach to low-amplitude seismic signals from coal-mines gives us the possibility of P phase arrival detection. For such a low-amplitude signals this method is more reliable than currently use in coal-mine tremor stations. However due to very nonstationary character of these signals it is difficult to give one general solution. Therefore future work will be on chosing the best wavelet for particular channel in seismic acquisition system. Also denoising can be improved by choosing the best-basis for seismic signal denoising using wavelet packet transform. In this case wavelet transform is apply to both the detail and the approximation coefficients resulting in an expansion of the decomposition tree to the full binary tree.

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References

[1] Isakow Z., Cianciara B., „Contribution of the EMAG Centre to development of the system for eval-

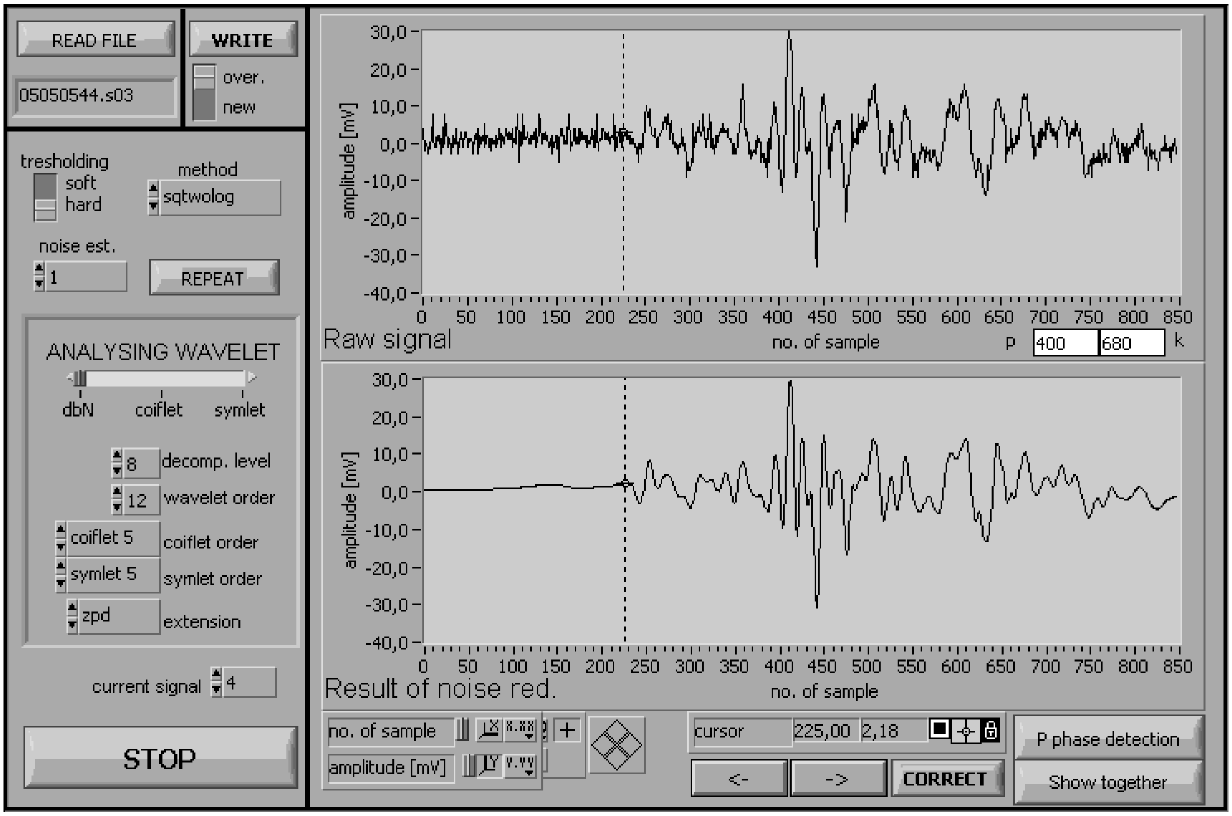

Figure 7: Front panel of program for signal denoising and P phase arrival detection.

uating bump hazards and monitoring of the effects of underground working on the surface of minefield", *Mechanizacja i Automatyzacja Górnictwa*, Vol. 9-10, pp. 146-159, 1999. (in Polish)

[2] Allen R., „Automatic earthquake recognition and timing from single traces", *BSSA*, 68, pp. 1521-1532, 1978

[3] Allen R., *Automatic earthquake recognition and timing from single traces*, *BSSA*, 68, pp. 1521-1532, 1978.

[4] Earle P. S., Shear P. M., „Characterisation of global seismograms using an automatic picking algorithm", *BSSA*, 84, pp. 366-376, 1994.

[5] Anant K. S., Dowla F. U., „Wavelet transform methods for phase identification in three-component seismograms", *BSSA*, pp. 1598-1612, 1997.

[6] Oonincx P. J., „Automatic phase detection in seismic data using the discrete wavelet transform", *Centrum voor Wiskunde en Informatica*, Report PNA-R9811, 1998.

[7] Chui C. K., *An introduction to wavelet*, Academic Press, 1992.

[8] Teolis A., *Computational signal processing with wavelets*, Birkhäuser, Boston 1998.

[9] Mallat S., *A wavelet tour of signal processing*, Academic Press, London 1999.,

[10] Mallat S., „A theory of multiresolution signal decomposition: The wavelet representation", *IEEE Trans. Pattern Anal. Machine Intell.*, pp.674-693, 1989.

[11] Wyżgolik R., „Wavelet analysis in sensor signal processing", *SPIE Proceedings*, Vol.4516, pp. 315-322, 2000.

[12] Donoho D., „De-noising via soft thresholding", *IEEE Trans. on Inf. Theory*, Vol.41, pp. 613-627, 1995.

[13] Donoho D., Johnstone I., „Adapting to unknown smoothness via wavelet shrinkage", *J. American Statistic. Assos.*, Vol. 90, pp. 1200-1224, 1995.