Development of Mathematical Algorithm for Seismoacoustic Signals Identification Using Local Geomechanical Control Means

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Abstract. This article reviews a creating of algorithm for the automatic seismoacoustic signals identification. The developed algorithm will be part of the software multi-channel device. The useful signals detection problem from the geomechanical state data stream is solved by determining the moments of impulses beginning and ending. The initial moment of time is determined using fast and slow exponential moving averages, used to smooth out data variations and the characteristic signal-to-noise ratio. The moving average method is used in conjunction with an adaptive threshold, which improves the accuracy of determining the initial moment and takes into account the noise. The last time instant of the useful signal is detected with the help of a cumulative envelope. The time of impulse beginning detection is calculated and terminated when the threshold value is reached. The developed mathematical algorithm allows to identify seismoacoustic signals with sufficient accuracy and is an undemanding hardware resource of the device that allows using it in real time.

1 Introduction

The process of mining must be accompanied by continuous monitoring of rock massive state to ensure safety [1-3]. Geomechanical monitoring systems are one of most perspective ways of such control in underground mining. They have high efficiency and low labor intensity, are used in various geological conditions and provide sufficient accuracy of geodynamic data.

Local control devices stand out among the wide range of geomechanical systems. They solve the task of operational short-term forecast of the impact hazard in underground mining.

The local monitoring device Prognoz L is a prominent member of the class of shock hazard control devices. It was developed at the Mining Institute of the Far East Branch of the Russian Academy of Sciences and combines modern technical means and flexible software [4, 5].

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However, despite the advantages of the device Prognoz L, in the process of long-term use, the need for modernization was formulated, including design, software and hardware improvements [6, 7].

2 Problem statement

Modernization of the local control device consists in improving the quality and reliability of the impact hazard prediction of a mountain range, with the ability to locate sources of seismoacoustic events and determine the parameters of the source of their occurrence [8-10]. This task is solved by expanding number of geomechanical state recording channels, expanding dynamic and frequency ranges and developing analytical algorithms for analyzing seismoacoustic data in real time and determining parameters of individual impulses, impulse groups, and zones. New effective method of assessing the impact of local control means will create a safer environment for mine personnel.

A simplified block diagram of seismic acoustic data processing by a local instrument is shown in Figure 1.

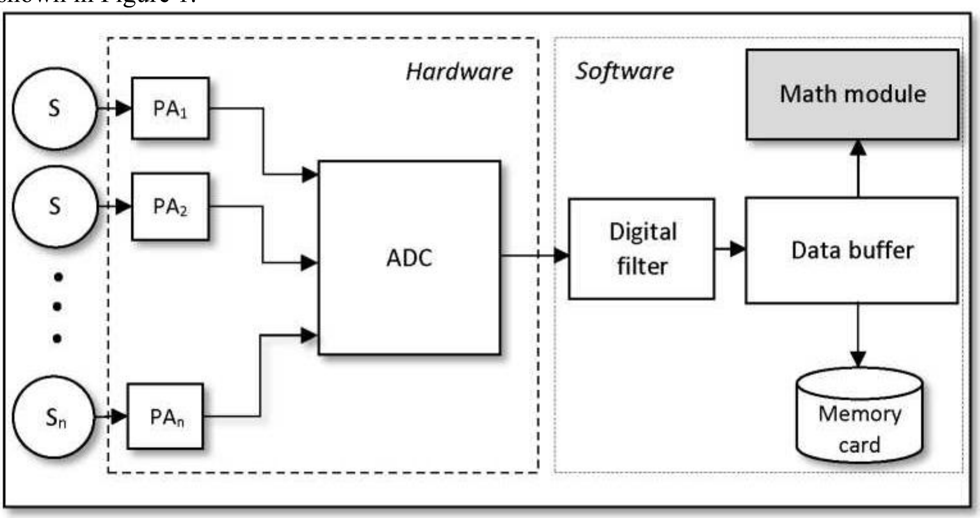

Fig. 1. Simplified block diagram of seismic data processing. S1-Sn - sensors, PA1-PAn - preamplifiers

In this paper, the task is to develop algorithms for the effective identification of seismoacoustic signals with the calculation of their parameters in a noise environment of a natural and man-made nature.

We use the software package for solving the problems of technical calculations MATLAB and the same name programming language for digital data processing.

3 Parametric description of seismic signal

It is necessary to designate the characteristics of the impulse at the initial stage. Consider Figure 2. It is a section of seismic acoustic data with a pronounced front.

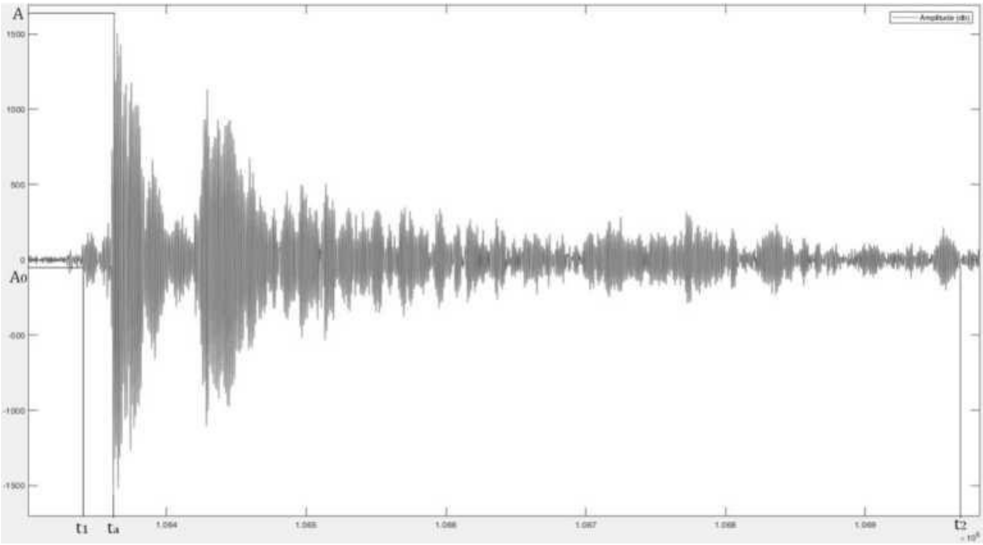

Fig. 2. Seismoacoustic impulse waveform: ti and t2 - respectively, the beginning and end of the signal, ta - time with a maximum amplitude, A - amplitude of the signal, A0 - the amplitude of the noise background

The parametric signal description contains the following characteristics.:

- t_1, t_2 - time moment of beginning and end of the signal;
- t_2 - t_1 - signal duration;
- t_a - time moment with the maximum amplitude;
- t_a - t_1 - signal front duration;
- A - signal amplitude;
- A_0 - average amplitude of the noise background;
- oscillation number;
- signal area, $\int_{t_1}^{t_3} A(t)$.

4 Adaptive threshold STA/LTA detector

It is required to determine the moment of useful signal waves arrival to successfully identify the seismoacoustic impulse. This task is complicated by the measurement environment, which is noisy with an average amplitude of A_0. Therefore, it is necessary to effectively filter out the interference generated as a result of the overlapping of natural and man-made noise.

It is considered data part before the formation of the useful signal waveform. It is presented in Figure 3.

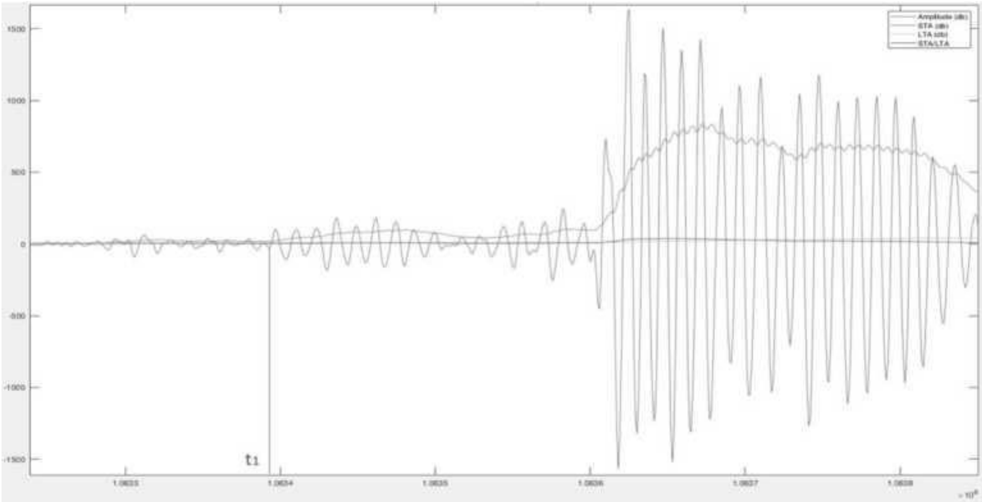

Fig. 3. Starting portion waveform of the seismic signal with a prehistory

We use the STA/LTA (Short Time Average to Long Time Average) method to automatically determine the signal beginning. He is considered in the Freiberger's and his followers works [11]. The method involves the calculation of the average values of the amplitudes in the short and long-time windows:

$$SMA(t) = \frac{1}{n}\sum_{i=0}^{n-1}|y(t-i)| \tag{1}$$

where $SMA(t)$ - the moving average value in the time point t;
n - number of samples in a short (long) time window or smoothing interval;
$y(t-i)$ - signal amplitude value in $t-i$ point.

This method is not demanding on computing resources. This allows it to be used in real-time systems [12]. However, it is proposed to process the signal from the ADC in parts and use exponential moving averages calculated by the formula:

$$EMA(t) = \propto \cdot\, y(t) + (1-\propto) \cdot EMA(t-1) \tag{2}$$

где *EMA(t)* -exponential moving average value in the time point t;
$\propto$ - characterizing the rate of decrease of amplitude coefficient or smoothing constant, $0 < \propto < 1$;
$y(t)$ - signal amplitude value in the current point *t;*
$EMA(t-1)$ - exponential moving average value in previous time point $t-1$.

This solution allows you to more reduce hardware requirements and improve computing performance. This solution allows you to more reduce hardware requirements and improve computing performance. The use of exponential moving averages reduces algorithm complexity with $O(N)$ for simple moving averages, where N is the number of points of the record being analyzed, to $O(1)$ for exponential. Therefore, the algorithm will work for a constant time.

Like this, we can determine the value of fast (STA) and slow (LTA) exponential averages. The constants for the determination of STA, LTA are determined empirically by processing a multitude of seismic acoustic data and are equal for the sampling frequency of

100 kHz 0.001 and 0.2, respectively.

The STA/LTA parameter allows us to estimate signal-to-noise ratio at a particular time moment. Therefore, the point in time when the condition $r(t_1) \geq c > 1$ is fulfilled, where c is threshold value determined empirically, and depends on measurement conditions, $r(t_1) = STA(t_1)/LTA(t_1)$ is the ratio STA/LTA at time t_1 is the beginning of the seismic signal. Figure 4 shows the starting part of impulse waveform, the graphics of the STA/LTA detector functions and the adaptive threshold, and also highlights the useful signal point area.

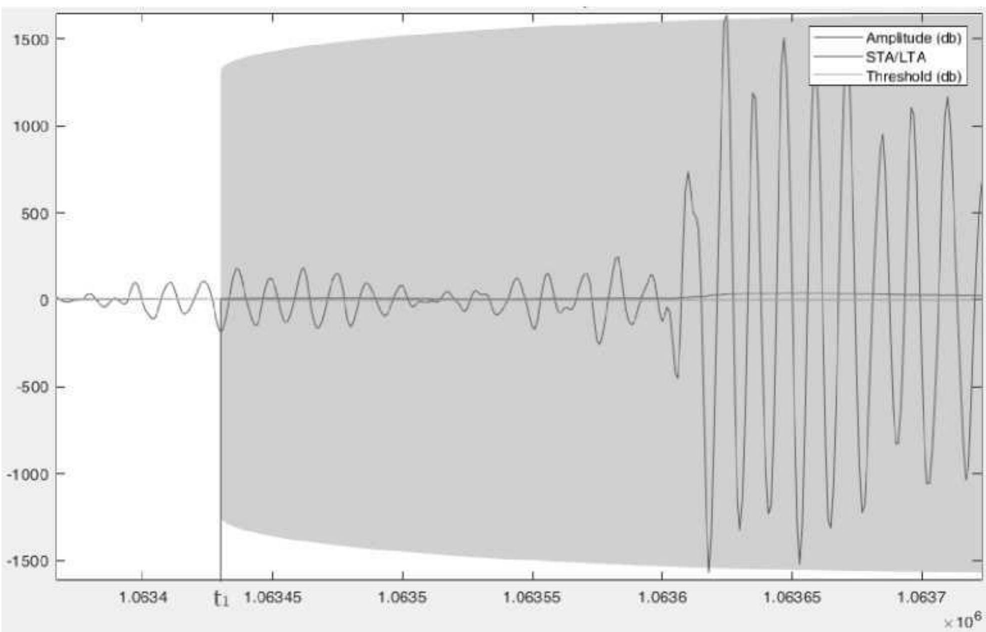

Fig. 4. Starting part of impulse waveform with signal-to-noise ratio and threshold

The threshold line is set as a constant according to Freiberger's works. On the one hand, reducing the threshold value will increase the calculation accuracy, and, on the other hand, will increase number of spurious signals.

To solve this problem, it is proposed to use an adaptive threshold value [13, 14], defined by the formula:

$$c(t) = EMA06(t) + EMA02(t) \cdot 0.05 + c_h \tag{3}$$

where $EMA06(t)$, $EMA02(t)$ - exponential moving average values; their smoothing coefficients are determined depending on the constant value of the preceding seconds and the signal sampling rate;

c_h - offset detector threshold, it prevents spurious signals and is determined empirically.

The STA/LTA detector allows us to automatically determine the beginning of a seismoacoustic impulse in real time, or based on already saved data.

5 Definition of seismoacoustic signal duration

The next step in the identification of the useful signal is the determination of the moment of the end of the pulse. To achieve this goal, it is proposed to use the concept of the cumulative envelope of the STA/LTA ratio [12], calculated using the formula:

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$$cs(t) = \sum_{i=I}^{k} log_2[b \cdot r(t-i)] \tag{4}$$

where $b < 1$ - $cs(t)$ function constant.

Therefore, the point in time t_1 when the condition $t > t_0$ и $cs(t) \leq 0$ is fulfilled will be the end of the useful signal. From this moment on, the calculation of the $cs(t)$ function is stopped and the beginning of the next useful signal is searched for. The algorithm for searching for the end of a signal is executed during amortization time and its complexity is $O(\alpha(n))$.

Figure 5 shows an example of calculating the cumulative envelope function.

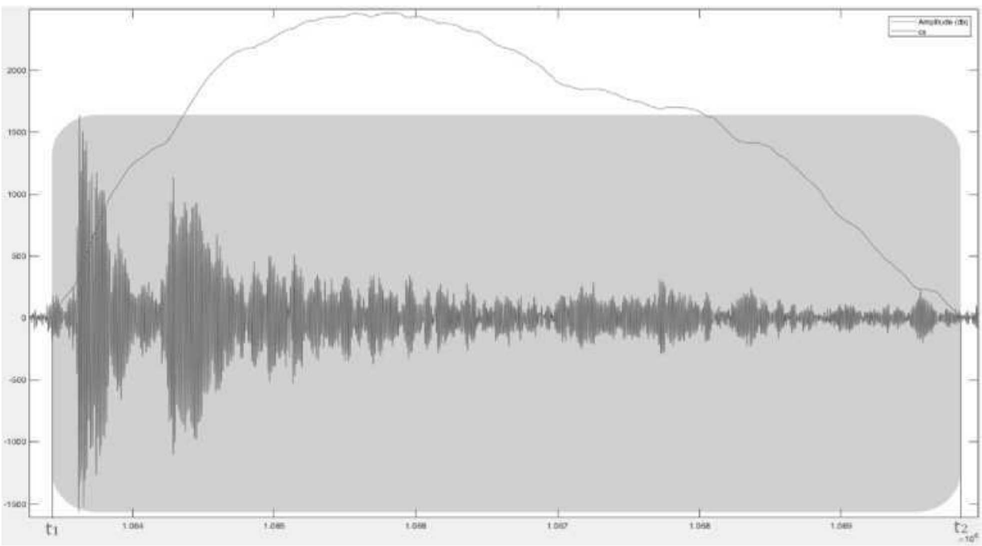

Fig. 5. Waveform seismic signal with the cumulative envelope function

6 Conclusion

The developed algorithm for the identification of seismoacoustic signals allows determining with sufficient accuracy the moments of the beginning and end of a useful signal; is undemanding to the hardware resources of the device and can be used with any amount of input data. Further work is planned to refine and improve the algorithm: a more accurate determination of the beginning of the signal by varying the constant values of moving exponential averages and calculating additional characteristics of impulses, for example, the area under the signal envelope (MARSE).

The identification of useful signals and the determination of their parametric characteristics is an important part of the developed methodology for controlling impact hazard in rock massif and device software.

7 References

1. A. N. Shabarov, S.V. Cirel, A. O. Rozanov, K. V. Morozov, I. Yu. Rasskazov, Physical and Technical Problems of Mineral Development, 9, 59 (2017)
2. A. Yu. Cheban, Mine Surveying and Subsoil Use, 4, 23 (2017)
3. A. Yu. Cheban, Improving the Technology and Technology of Non-Explosive Rock

Mining (Khabarovsk, 2017)
4. A. A. Tereshkin, A. Yu. Rasskazov, P. A. Anikin, D. S. Migunov, Mining Information and Analytical Bulletin, 24, 338 (2017)
5. I. Yu. Rasskazov, A. V. Gladyr, D. S. Migunov, P. A. Anikin, A. A. Tereshkin, Certificate of registration of the computer program RUS 2017663503 (2017)
6. A. Konstantinov, VII International Scientific Conference Problems of Complex Development of Georesources, 02024 (2018)
7. A. V Konstantinov, A. V. Gladyr, Proceedings of the universities. Mining journal, 4, 24 (2019)
8. I. Yu. Rasskazov, S. V. Cirel, A. O. Rozanov, A. A. Tereshkin, A. V. Gladyr, Physical and Technical Problems of Mineral Development, 2, 29 (2017)
9. A. O. Rozanov, D. N. Petrov, A. M. Rozenbaum, A. A. Tereshkin, M. D. Ilinov, Eurock 2018. Geomechanics and Geodynamics of Rock Masses, 669 (2018)
10. I. Yu. Rasskazov, A. A. Tereshkin, A. V. Gladyr, S. V. Cirel, A. O. Rozanov, Journal of Mining Science, 2, 224 (2017)
11. M. Joswig, Bulletin of Seismological Society of America, 1, 170 (1990)
12. S. V. Baranov, Regional Bulletin of Young Scientists. Geophysics, 3 (2014)
13. A. A. Crasovsky, Digital Signal Processing, 3, 70 (2010)
14. A. B. Sergienko, Exponenta Pro. Math in Applications, 1, 18 (2003)