Comparative analysis of algorithms of processing luminescence signals from minerals for diamond detection in ore flow

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Abstract

In diamond mining the effectiveness of diamond extraction from ore is mainly determined by algorithms of processing luminescence signals from minerals, what requires investigation into effectiveness of the algorithms. The article is devoted to results of MathCAD modeling of the digital algorithms of signal processing which are currently used in X-ray luminescent diamond separators. The modeling is a basis for the algorithms’ effectiveness assessment and comparative analysis with the traditional analog methods of signal processing used in X-ray luminescent diamond separators. The authors also consider a question of temporal signal resolution of luminescence from minerals.

Keywords: Diamond separator, separation, digital processing of signals, X-ray luminescence

1. Introduction

In diamond mining a technology of X-ray luminescent enrichment of diamond-bearing ore has been widely spread. It is a key technology applied by diamond mining enterprises in Russia and there is a great push for its further development [1, 2], because this technology is not only highly productive but also ecologically friendly and could be easily automated.

The basis of the technology is the well-known quality of diamonds to luminesce when exposed to X-ray radiation. The luminescent signals are used to separate diamonds from ore (Fig. 1). The separators’ control system has long been computerized but up to the time being it has used mainly analog methods of signal processing. When high-performance signal processors, microcontrollers with RISC architecture and developed periphery became available it has made digital processing of signals possible. Producers like ULTRASORT, OSNA and DEBEX have already mastered industrial production of digital separators. Russian editions [2, 3] have also published issues on X-ray luminescent separators with digital signal processing based on digital algorithms. Unfortunately the publications do not have information on the effectiveness of the algorithms offered in comparison with analog ones. In this article the authors carry out effectiveness assessment of some digital algorithms for signal processing and compare analog and digital processing methods. Temporal signal resolution of luminescence from minerals in diamond separation process will also be considered.

Tackling the questions indicated above is very important for understanding of perspective of digital signal processing in development of more effective algorithms for diamond-bearing ore enrichment.

2. Signal processing algorithms

The signal processing algorithms used in X-ray luminescent diamond separators serve the purpose of signal detection against a background of noises, luminescence compensation of air in the radiation zone and the cutoff plates time gaps, etc. In this article the authors have concentrated on that part of the algorithm, which describes the process of signal detection against a background of noises.
In the analog separators signal detection against a background of noises is carried out through signal averaging either in ordinary integrating circuit or in low-pass filter. In the digital separator described [3] detection against a background of noises is a combination of procedures of median filtering and averaging [4] that are software-realised. This part of the algorithm is presented in Fig. 2, where \( f_n \) is a quantized signal at instant \( nT \); \( n \) is a sequence of natural numbers; \( T \) is a signal sampling period; \( Y_n \) is a signal after median filtering; \( \overline{Y}_n \) is a signal after moving average process; \( l \) is the size of averaging window.

The algorithm (Fig. 2) suggests digitization (1), median filtering (2) and averaging (3). When studying its effectiveness the authors modeled as the whole algorithm as its separated operations and their combinations. For comparative analysis of the analog and the digital methods the authors used averaging procedure (3) (see Fig. 2).

The modeling has been made with a set of standard MathCAD functions and is a mixture of real noise and a square wave signal, imitating a real signal. The model is presented in Fig. 3. Signal-to-noise ratio \( SN \) after processing original model signal has been determined by the following formula:

![Fig. 1. The diamond separation process.](image1)

![Fig. 2. Algorithm of signal detection against a background of noises.](image2)

![Fig. 3. Model: signal with real noise.](image3)
\[ SN = A / \left( \frac{1}{N} \sum_{i=0}^{N} h_i^2 \right)^{1/2}, \]

where \( A \) is an amplitude of the output signal processed, \( N \) is a value of signal array, \( h_i \) - \( i \) - reference value of output noise after processing.

In the process of modeling, graphs displaying dependence of change in SN ratio of the signal processed on the size of the moving window for different types of processing (median filtering, averaging and a combination of the two) were built.

![Graph Dependence of SN ratio of a signal processed on the size of k window.](image)

The graphs are presented in Fig. 4 where sets of curves SN1 (solid lines), SN2 (dotted lines) and SN3 (chain lines) correspond to input signals with ratio SN 1.42; 1.77 and 2.48 correspondently. In each of the sets the bottom part corresponds to averaging, middle – to median filtering, the top part- to the process of median filtering followed by averaging of the signal processed.

Figure 4 shows that all the dependencies have non-linear character with asymptotic behavior in the areas of big moving windows. When median filtering and averaging are applied separately starting from moving window to be of the size about 8 bin (single tics) the biggest SNR has been secured through median filtering. Median filtering prevails averaging the bigger the size of the window. Successive application of averaging after median filtering has resulted in insignificant growth of signal-to-noise ratio. For instance, for windows with the size of 16 and 32 bin SNR of output signal growth constitutes \( \approx 5\% \) and \( \approx 3\% \) correspondently (for output signal with SN = 1.77).

**Temporal resolution of signals.** When modeling and analyzing temporal resolution of luminescent signals from minerals, the authors used a set of pairs of square signals with intervals changing between the pairs. Authors took \( Q \) to be criterion of temporal resolution and determined as:

\[ Q = \delta / A, \]

where \( A \) is an amplitude of test impulse after, \( \delta \) - a dip of the signal in a pair of impulses after processing. Analysis and comparison of the temporal resolution have been made for the rectangular moving window and smoothing Hamming \( X(i) \), Blackman \( B(i) \), and Gauss \( G(i) \) windows [5]:

\[ X(i) = 0.54 - 0.46\cos(2\pi i / k), \]
\[ B(i) = 0.42 - 0.5\cos(2\pi i / k) + 0.08\cos(4\pi i / k), \]
\[ G(i) = \exp[-(i - \Delta)^2 / a], \]

where: \( \Delta = (k + 1) / 2; \ k \) is the size of the window in bins; \( a \) – a parameter of Gaussian function.
One can observe the smoothing windows in Fig. 5, where the solid line is a rectangular P window, the dotted one – (X) Hamming window, the dashed line – (B) Blackman window and the chain one corresponds to (G) Gauss window. \( k = 32 \text{ bin}, \) for gauss window \( a = 50. \)

![Fig. 5. The windows: appearance.](image)

Fig. 6. The way a type of the smoothing windows affects the temporal resolution. Top graph – the Blackman window. Bottom graph – the rectangular window.

The analysis has been made with the use of the algorithm, represented in Fig. 2, where, between procedures 1 and 3 one implemented multiplication for the smoothing window of \( k \) size. Observing the Blackman windows and the rectangular window in Fig. 6 one can see the dip of the signal increase from one pair of the impulses to the other. So, temporal resolution of the signals can be determined as dependence on relative value \( R \) that is described by the following formula:

\[
R = \lambda / k ,
\]

where \( \lambda \) is time gap between the impulses in a single test pair at the input.

The dependence of \( Q \) on \( R \) for different types of the windows can be seen in Fig. 7.

![Fig. 7. The dependence of \( Q \) on \( R \) for different types of the windows: rectangular window (solid line), Hamming window (dotted line), Blackman window (chain line) and Gauss line (hatch).](image)

Comparison of the graphs shows the worst temporal resolution for the rectangular window, one that is traditionally used in X-ray luminescence diamond separators [3]. The window has reached resolution of about 95% only when \( R \) amounts up to 1. At the same time
the Gauss window has reached the same resolution at R equal to 0.57. This calls for using smoothing windows like Gauss or Blackman ones for signal processing in X-ray luminescence diamond separators. It also should be mentioned that using median filtering in the algorithm (Fig. 2) does not allow determining dips between the impulses with $\lambda \leq k/2$ and $R \leq 0.5$. One can see that in Fig. 6 and Fig. 7.

But despite this disadvantage medial filtering is important for pulse interference blanking and using the smoothing windows allows decreasing the effect the disadvantage has on temporal resolution of the signals.

3. Conclusion

Using MathCAD modeling tool the authors have obtained dependencies of changes in signal-to-noise ratio of the signal processed on the size of the moving window for medial filtering, averaging, and a combination of the two. The results obtained can be helpful in choosing a way of signal processing for a digital diamond separator.

When the processes of median filtering and averaging are applied separately, with the size of the smoothing window about 8 bin, the most increase in SNR is secured by median filtering. And it keeps prevailing averaging the bigger the size of the window. For instance, for a window with the size of 8 bin median filtering and averaging increase SN ratio by $\approx 30\%$ and $\approx 48\%$ correspondently. For a window of 16 bin the values are $\approx 34$ and $\approx 65\%$ correspondently.

In case median filtering is followed by averaging with the same size of a window, additional increase in SNR has been insignificant. For instance, for a window with the size of 16 and 32 bin additional increase in SNR has been $\approx 5\%$ and $\approx 3\%$ correspondently (for input signal with SNR equal to 1,77).

The worst temporal resolution has been demonstrated by the signals, which were processed with the rectangular window that is traditionally used in X-ray luminescent diamond separators. To increase the resolution one should apply windows of other type (Gauss or Blackman) for signal processing.

References