Size correction of fuzzy classifier rules area by dispersion value of ultrasonic measurements results in ore mineral varieties determining

Vladimir Morkun

Vice-Rector for research,
Doctor of Science, Professor,
Professor of Computer Science, Automation and Control Systems department,
Kryvyi Rih National University,
Kryvyi Rih, Ukraine

Natalia Morkun

PhD, Associate professor of Economic Cybernetics and Project Management Department,
Kryvyi Rih National University,
Kryvyi Rih, Ukraine

Nikolai Podgorodetsky

PhD, Associate professor of Labor Protection, Life Safety and Civil Protection Department,
Donbas National Academy of Civil Engineering and Architecture,
Ukraine

Abstract
An accuracy increasing method of processed ore mineral varieties determination based on subtractive clustering of its features with the correction of fuzzy rules region dimensions by the evaluation of intensity dispersion of high-frequency volume ultrasonic vibrations, which passed a fixed distance in a controlled volume of pulp is proposed.
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To solve the problem of increasing the accuracy of fuzzy classification method of object characteristics based on subtractive clustering algorithm, it is necessary to perform the optimization of the vector, which determines the rules region dimensions for each coordinate, and if necessary, adjust it during observations [1-6]. Let's consider the procedure of setup and correction of rules region dimensions of subtractive clustering by observation results dispersion value on example of pulse parameters measurement of ultrasonic waves passed through a controlled volume of pulp. As is known, the function describing the harmonic wave, which propagates in nondispersive media is written as [5]

$$u(x,t) = A\cos(kx - \omega t), \tag{1}$$

where $k = 2\pi/\lambda$ – is the wave vector;$\omega = 2\pi/T$ – is the circular frequency; T –is the wave period.

Analysis of (1) shows that we can enter a phase function of cosine traveling wave, which propagates in the positive direction of OX axis as the argument of the wave function

$$\phi(x,t) = \omega t - kx. \tag{2}$$

To track any wave crest (max $\cos\phi(x,t)$) or for its trough (min $\cos\phi(x,t)$), with an increase in time it is necessary to proceed to increasing value of x so that the phase $\phi(x,t)$ is constant. Phase constancy condition from a mathematical point of view means that the total differential of function $\phi(x,t)$, which has the form

$$d\phi = \left(\frac{\partial\phi}{\partial t}\right)dt + \left(\frac{\partial\phi}{\partial x}\right)dx = \omega\,dt - kdx, \tag{3}$$

is equal to zero. By equating (3) to zero, we find the condition of phase constancy

$$\frac{dx}{dt} = v_f = \frac{\omega}{k}, \tag{4}$$

where v_f –is the phase velocity of the wave.

Equation (4) establishes a relationship between the phase velocity of the wave, wave frequency and wave vector. Wave propagation conditions are determined by medium properties. Thereby ω, and phase velocity are dependent on the wave vector *k.* A dispersing wave, which represents a superposition of traveling waves with different wave numbers, changes its form in space in process of distribution as components of different wavelengths travel at different velocities. Let's consider an ultrasonic pulse movement in a dispersive medium, by which we mean a certain sine wave, which have a finite extent in both space and time. The solution to this problem is based on the representation of the wave packet as a superposition of harmonic functions (Fourier method) [7-9]. Let's denote the intensity of an ultrasonic signal during it passing a fixed distance z in the pulp by

$$I_z = I_0 \exp\left\{-\frac{1}{V}\sum_{i=1}^{k}\sigma(r_i)z\right\}, \tag{5}$$

where $\upsilon(r_i)$ – is the ultrasound absorption cross section by particles with radius of r_i.

The dispersion of this value is given by

$$DI_z = M(I_z - \langle I_z \rangle)^2 = MI_z^2 - \langle I_z \rangle^2. \tag{6}$$

For a fixed number of crushed material particles in a controlled volume V [6, 10]

$$M(I_z^2) = I_0^2 \exp\left\{-nV(1 - \int_0^\infty e^{-\frac{2}{V}\sigma(r)z} F(r)dr)\right\}. \tag{7}$$

Let

$$\psi = \exp\left\{\frac{nz^2}{V}\int_0^\infty \sigma^2(r)F(r)dr\right\}. \tag{8}$$

Then

$$DI_z = I_0^2 \exp\left\{2nz\int_0^\infty \sigma(r)F(r)dr\right\}\left[\psi^2 - \psi\right]. \tag{9}$$

We will determine the relative value

$$\frac{\sqrt{DI_z}}{\langle I_z \rangle} = \frac{I_0 \exp\left\{-nz\int_0^\infty \sigma(r)F(r)dr\right\}\sqrt{\psi^2 - \psi}}{I_0 \exp\left\{-nz\int_0^\infty \sigma(r)F(r)dr\right\}\sqrt{\psi}} = \sqrt{\psi - 1}. \tag{10}$$

$$\ln\frac{I_0}{\langle I_z \rangle} = z\phi_s \frac{\int_0^\infty \sigma(r)F(r)dr}{\int_0^\infty 4/3\pi r^3 F(r)dr}. \tag{11}$$

$$S_D = \frac{\ln\psi}{\ln I_0/\langle I_z \rangle} = \frac{z}{V}\frac{\int_0^\infty \sigma^2(r)F(r)dr}{\int_0^\infty \sigma(r)F(r)dr}. \tag{12}$$

Let's define the characteristic function

The last expression shows that the value of S_D is defined by intensity dispersion DI_z of ultrasonic signal, which passed a fixed distance z in a controlled medium. Value of S_D is a function of the crushed ore particle size and doesn't depend on its solid phase concentration. Let the function, which is describing the traveling wave at the point $x = 0$, has a known time dependence $f(t)$

$$f(t) = u(0,t). \tag{13}$$

Let's assume that wave packet is localized in time, i.e. the envelope of the package is a function, which is quickly tending to zero at $t \to \infty$. This assumption allows us to represent the function $f(t)$ as a Fourier integral [11-15]

$$f(t) = \int_0^\infty A(\omega) e^{i\omega t} d\omega, \tag{14}$$

where

$$A(\omega) = \int_0^\infty f(t) e^{-i\omega t} dt. \tag{15}$$

Each harmonic determines its own harmonic traveling wave with wave number k, the value of which is determined by the dispersion relation

$$k = k(\omega). \tag{16}$$

Here, each traveling wave frequency component propagates with the phase velocity

$$v_f = \frac{\omega}{k(\omega)}. \tag{17}$$

The desired function $u(x,t)$, which describes the traveling wave is a superposition of these harmonic traveling waves. This means that finding of $u(x,t)$ is possible by replacement ωt on $(\omega(k)\, t - kx)$ in each harmonic component of superposition (15)

$$u(x,t) = \int_0^\infty A(\omega) e^{i(\omega t - k(\omega)x)} d\omega. \tag{18}$$

It should be noted that the calculation of the integrals in (14), (16) and (18) should be carried out at time intervals of finite length of T, i.e. perform the expansion of the function in a Fourier series, using the following expression

$$f(t) = \sum_{n=0}^{N-1} A(n) e^{i(2\pi/T)nt}, \tag{19}$$

$$A(n) = \frac{1}{T} T \int_0^T f(t) e^{-i(2\pi/T)nt} dt, \quad n = 0,1,\ldots,N-1, \tag{20}$$

$$u(x,t) = \sum_{n=0}^{N} A(n) e^{i[(2\pi/T)nt - k((2\pi/T)n)x]}, \tag{21}$$

where N – is the number of function $f(x)$ values.

To speed up the computation of the coefficients $A(n)$ it is possible to use a Fast Fourier Transform (FFT). Thus, the numerical solution of the problem of wave packet motion in a medium with a dispersion relation of the form $\omega(k) = k + \alpha k^2$ is in accordance with the following algorithm:

- set the function $f(t)$, which describes the initial disturbance at $t = 0$;
- set the function $k = k(\omega)$ (at impossibility of analytical inversion of dispersion relation $\omega = \omega(k)$,one should find numerically the corresponding value of the wave number, as the root of the equation $\omega_s = \omega(k)$) for each frequency setpoint $\omega_s = 2\pi s/T, s = 1,\ldots N$;
- set boundaries of time interval on which a solution of problem is sought.
- specify the number of time grid nodes;
- calculate the values of the function $f(t)$, in time grid nodes;
- calculate the expansion coefficients of the function $f(t)$ in a Fourier series;
- calculate the values of the function $u(x,t)$ at a given time in accordance with (21).

Fig. 1 shows real and imaginary parts of the original pulse, and Fig. 2 shows the envelopes of wave packet at various points of x of measuring vessel, which were determined according to the algorithm given above. Analysis of the results shows that the wave packet is localized in the interval [18 ... 62].

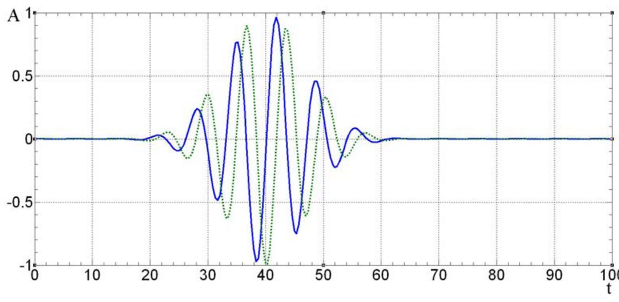

Figure 1. The imaginary and real parts of the initial ultrasound pulse

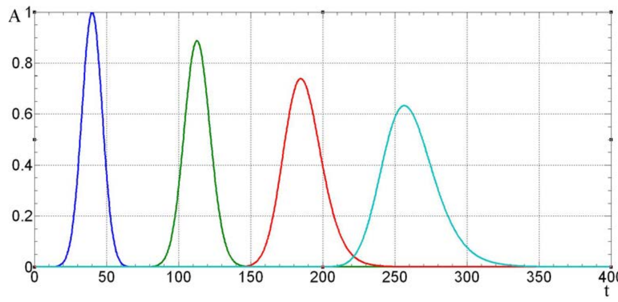

Figure 2. The envelopes of the wave packet at different time points

In the process of movement the wave packet shape is changing: there is a decrease in height of packet envelope while increasing its width (the spread of wave packet in the space caused by dispersion properties of the medium - variations of the crushed ore particle size characteristics in the pulp) [16-18].

Conclusions

The proposed method allows to identify mineral varieties of processed ore in the process initial stage with high degree of accuracy, to compare it with respective technological regulations and predefined optimum separation characteristics of classifying and processing apparatus, and thus achieves the specified parameters of beneficiation while maximizing productivity and efficiency.

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