Adaptive control system of ore beneficiation process based on Kaczmarz projection algorithm

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Abstract
Using of Kaczmarz projection method and its modifications based on sequential orthogonal approximation projection on the hyperplane for the synthesis of adaptive control systems of iron ore beneficiation processes is described.
KEY WORDS: PROJECTION ALGORITHM, PULP, CONTROL, KACZMARZ, BENEFICIATION

Optimization of the mineral processing processes requires first of all the creation of rigorous mathematical and economic-mathematical methods for calculating the optimal separation boundaries φ_{ropt} of physical properties variation region of the feedstock particles [1]. The solution of this problem allows to determine both the best structure of the beneficiation production line and parameters of technological units, providing its maximum performance with a given quality of the final product and minimal costs to the process. The correct conclusions about the quality of technological process conducting can be done only on the basis of a fairly complete set of data about extraction of raw material classes various by composition and size in specific conditions of processing industry.

To extract the information about the behavior in a separation zone for such complex particle system as actual pulp, it may be represented by a set of fractional extracts or separation numbers by each elementary particle category (class) with the known separation parameter and the particle size. On the basis of these data we can regulate the process of beneficiation. Thus, the most accurate estimation of the performance of processing industry technological aggregates can give the information about the useful component content across the spectrum of particle size characteristic of the processed ore [4,5]. Since this characteristic is a function with a large number of input and output parameters, the model of these object is of high dimensionality, which makes it inconvenient for analysis and use in the process control formation.

Among the many existing methods for the solution of such class of problems the special place belongs to projection methods. Due to its sufficient flexibility, as well as a number of advantages, the projection methods are gaining increasing popularity [5-11].

Let's consider the possibility of using an iterative Kaczmarz method for the synthesis of adaptive control systems of iron ore beneficiation processes. The classic version of this method reduces to solving of linear algebraic equations systems with a square nonsingular matrix via sequential orthogonal approximation projection on the hyperplane.

$Au = f$, $A = \{a_{i,j}\}$, $u = \{u_i\}$, $f = \{f_i\}$, $i, j = 1, 2, \ldots, N$, (1)

with real vectors u, f and non-degenerate, in general, nonsymmetric matrix A [6].

Denoting by A_i i-th row of the matrix A, resulting in system (1) can be rewritten as

$$\left(Au\right)_i = \left(u, \mathrm{A}_i^t\right) = A_i u = f_i,\ i-1,2,...,\mathrm{N}, \quad (2)$$

then the Kaczmarz method defined as follows (in (2) A_{ti} means the transpose to A_i column vector, and (·,) - is a common vector scalar product).

Let $u^{n-i} = \left\{u_i^{n-1}\right\}$ is the vector of (n-1)-th iterative approximation, which is also redenoted as $u^{n,0}$. Then the new n-th iteration is defined for N consecutive steps:

$$u^{n,i} = u^{n,i-1} + A_i^t r_i^{n,i-1}, i-1,2,...,\mathrm{N},$$
$$u^n = u^{n,N}, \quad (3)$$

where $r_i^{n,i-1} = f - Au^{n,i-1}$ is the residual vector of corresponding approximation.

This algorithm has a simple geometric interpretation. Each of the equations (2) in the N-dimensional real space R^N is a hyperplane. If the source system is non-degenerate, then all hyperplanes have a common single point of intersection, which is the solution of u.

This algorithm is determined by several advantages: it is simple in computation and requires small memory for implementation on a PC, low inertia, recurrently (allows to calculate in real time), allows to define accurately the parameters of an object, a sequence of parameter estimates, calculated with its usage, is monotonically converging to the true parameter values, there are possibilities to improve noise immunity, which are easy to implement by hardware and programmatically. The advantages identified widespread practical use of this algorithm in the automation of industrial plants.

Let's consider some modifications of this method, the purpose of which is to ensure the convergence speed, which is independent from the equations number in the system.

Kaczmarz algorithm with quasioptimal rule, based on the construction of the projection sequence is essentially a method of optimal coordinate descent in which descent is carried out on a one-dimensional subspace corresponding to the coordinate axes in the basis $\left\{\varphi_i = \frac{a_i}{\|a_i\|}\right\}_{i=1}^{m}$

The main computational complexity in this case is to find such φ_i, during the descent to which the residual will decrease significantly. To do this, after each iteration of the Kaczmarz algorithm it is necessary to make the calculation of all the vector of obtained residual and select the components of the error vector with the maximum absolute value.

The Kaczmarz algorithm with a randomized rule, in which each element of the projection sequence *j(k)* is a realization of a random variable of *J* with a discrete distribution law $P(J=i)=\|a_i\|_2^2 / \|A\|_F^2$, therefore there is a possibility that at the iteration with *k*-number the line with number *i*, which is proportional to the rate of the line will be used.

The results of solving the problem of processing production processes adaptive control using Kaczmarz classical algorithm and its two modifications are shown in Figure 1, as well the change in the control error value in the process of their implementation is shown in Figure 2.

The calculations for each of the three algorithms were examined using the rules of relative errors $\frac{\|u^k - u^*\|}{u^*} < \varsigma$, $\varsigma = 0{,}01$, where u^* is the exact solution of the problem, the relative error of the solution.

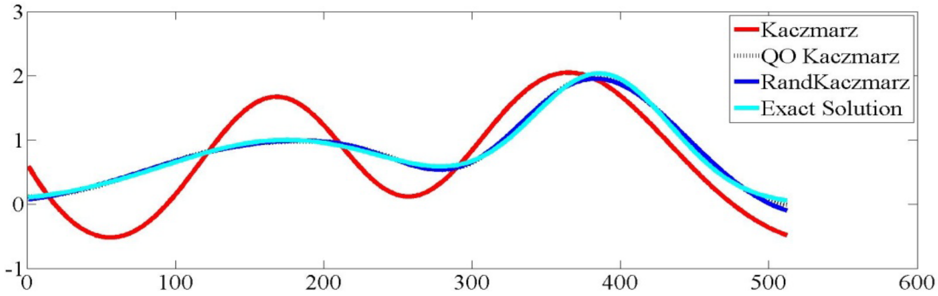

Figure 1. Modeling of beneficiation technological process control using the classical Kaczmarz algorithm

With the implementation of quasi-optimal algorithm the *m*- scalar products are computed in parallel at each iteration. Thus, in practice, the average time of one iteration was approximately only twice as much compared with the times of iterations of the other two algorithms, while quasi-optimal algorithm shows undeniable advantages compared with even a randomized algorithm for solving a particular problem.

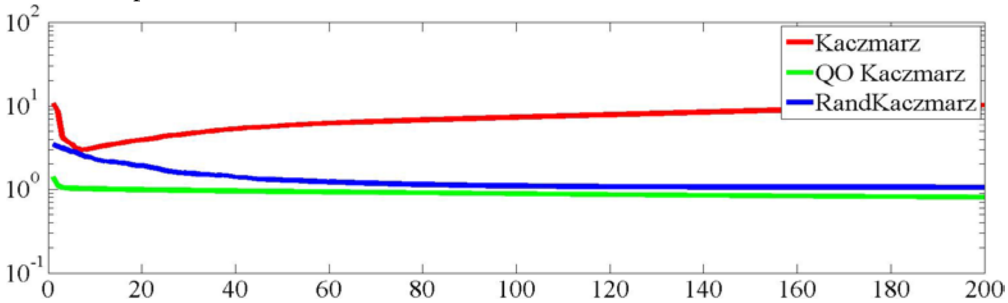

Figure 2. Change in the size of the control error in the process of implementing the Kaczmarz algorithm and its modifications

Conclusions

Thus, the Kaczmarz projection method based on sequential orthogonal approximation projection on the hyperplane can be effectively used for the formation of an automatic adaptive control of concentrating production processes. The simulation results have shown that this method does not require a priori knowledge of the process parameters and allows to maintain their values with an error not exceeding 1,2% and also reduce the duration of the transition processes in a closed-loop regulation system by 3-4%.

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