ONE METHOD OF THE RESERVES CALCULATION BY USING THE GAUSSIAN DISJUNCTIVE KRIGING

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Abstract: *disjunctive kriging (DK) has been known as one of non-linear geostatistics efficient than linear geostatistics and the non-linear estimators estimated by that is more correct than the linear estimators.*

In order to calculate reserves more accurately and conveniently, we set the size of estimating block at the reserves calculation area in consideration of the range given from the calculation result of experimental variogram. As we used only on the reserves calculation the blocks in which the estimators given by progressing the disjunctive kriging estimation are larger than the lowest industrial standard value on the each block, we solved the reserves calculation border establishment problem.

Keywords: *disjunctive kriging, reserves, reserves calculation.*

ОДИН ИЗ МЕТОДОВ РАСЧЁТА ЗАПАСОВ С ПОМОЩЬЮ ГАУССОВОГО ДИЗЪЮНКТИВНОГО КРИГИНГА

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Аннотация: *дизъюнктивный кригинг (DK) известен как одна из нелинейных геостатистик, более эффективная, чем линейная геостатистика, и оцененные по этой причине нелинейные оценки более правильны, чем линейные оценки.*

Для более точного и удобного расчета запасов мы устанавливаем размер оценочного блока в области расчета запасов с учетом диапазона, полученного из результата расчета экспериментальной вариограммы. Поскольку мы использовали только расчеты запасов, блоки, в которых оценки, полученные путем прогрессирования оценки дизъюнктивного кригинга, были больше, чем самая низкая

промышленная стандартная величина для каждого блока, мы решили проблему создания границы для расчета запасов.
Ключевые слова: *дизъюнктивный кригинг, запасы, расчёт запасов.*

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1. Process of the reserves caculation

1.1. Determination of reserves caculation index

The main index needed to estimate reserves are area, thickness, density and grade. The error in reserves caculation is made in case that main indices are not determined accurately.

Therefore, in order to keep the accurateness in reserves caculation, main indices to estimate reserves is determined accurately and the error must be decrease in the calculation.

In this paper, we selected the regionalized variable as the main index of reserves estimation and made Gaussian disjunctive kriging estimation.

①Based on the detailed survey for the geological composition and prospect state of deposit, indices of reserves caculation are selected to estimate reserves for each ore body, each level and each region.

In order to estimate accurately reserves, it must be analyzed synthetically all pre-existing exploration data and prepared the necessary maps and data for reserves estimation.

The scale of map of reserves caculation is generally 1:5000, 1:2000, 1:500 and rarely 1:10000.

②The measuring value from the exploration are synthesized along to every coordinate and its statistical distribution feature is evaluted.

1.2 Caculating method and procedure of reserves

1.2.1 Assumption and estimation of disjunctive kriging

Disjunctive kriging have several types and the most common type is the following Gaussian disjunctive kriging that suggested by a researcher [1].

The regionalized variable $z(x)$ is assumed as follows in Gauss disjunctive kriging.

First, the regionalized variable $z(x)$ is variate as realization of a second-order stationary process $Z(x)$ with mean m, variance δ^2 and covariance function $C(h)$.

Second, the bivariate distribution for the $n+1$ variates, i.e. for each target site and the sample locations in its neighbourhood, is known and is stable throughout the region. If the distribution of $z(x)$ is normal (Gaussian) and the process is second-order stationary then we can assume that the bivariate distribution for each pair of locations is also normal.

The first, task therefore is to transform an actual distribution, which may have almost any form, to a standard normal one, $Y(x)$.

$$Z(x) = \phi[Y(x)] \qquad (1)$$

Hermite polynomials can be expressed as follows.

$$H_k(y) = -\frac{1}{\sqrt{k}} yH_{k-1}(y) - \sqrt{\frac{k-1}{k}} H_{k-2}(y) \qquad (2)$$

The function of $Y(x)$ can be expressed as the sum of these Hermite polynomials.

$$Z(x)=\phi[Y(x)]=\sum_{k=0}^{\infty}\phi_k H_k\{Y(x)\} \qquad (3)$$

By kriging them separately the estimates have only to be summed to give the disjunctive kriging estimator.

$$\hat{Z}^{\mathrm{DK}}(x)=\phi_0+\phi_1\hat{H}_1^k\{Y(x)\}+\ \phi_2\hat{H}_2^k\{Y(x)\}+\cdots \qquad (4)$$

So, if we have n points in the neighbourhood of x_0 where we want an estimate, we estimate, we estimate by the equation

$$\hat{H}_k^k\{Y(x_0)\}=\sum_{i=1}^{n}\lambda_{ik}H_k\{Y(x_i)\} \qquad (5)$$

and we insert them into equation (4).

The λ_{ik} are the kriging weights, which are found by solving the equations for simple kriging because we can assume the mean is known.

$$\hat{Z}^{\mathrm{DK}}(x_0)=\phi[\hat{Y}(x_0)]=\phi_0+\phi_1[\hat{H}_1^k\{Y(x_0)\}]+\phi_2[\hat{H}_2^k\{Y(x_0)\}]+\cdots \qquad (6)$$

By equation (6), $\hat{Z}^{\mathrm{DK}}(x_0)$, the disjunctive kriging estimator at x_0 can be found.

Estimate variance can be found as follows.

The kriging variance of $\hat{H}_k\{Y(x)\}$ is

$$\delta_k^2(x_0)=1-\sum_{i=1}^{n}\lambda_{ik}\rho^k(x_i-x_0) \qquad (7)$$

And the disjunctive kriging variance of $\hat{f}[Y(x_0)]$ is

$$\delta_{\mathrm{DK}}^2(x_0)=\sum_{i=1}^{\infty}f_k^{\,2}\delta_k^2(x_0) \qquad (8)$$

Once the Hermite polynomials have been estimated at a target point, we can estimate the conditional probability that the true value that exceeds the critical value, Z_c.

$$\hat{\Omega}^{DK}[Z(x_0)>Z_c]=\hat{\Omega}^{DK}[y(x_0)>y_c]=$$

$$=1-G(y_c)-\sum_{k=1}^{L}\frac{1}{\sqrt{k}}H_{k-1}(y_c)g(y_c)\hat{H}_k^k\{Y(x_0)\} \qquad (9)$$

This can be estimated the probability that exceeds the lowest industrial standard such as lowest industrial standard grade or lowest industrial standard thickness, etc.

Through process like this, we can be performed the disjunctive kriging estimation for indices of reserves calculation and can be evaluated the reserves using estimators given from that.

1.2.2. Determination size of estimating block for the reserves evalution.

The boundary determination of reserves estimating area was very important problem in the traditional reserves evaluation. As the geostatistics develops, there are some difficult problems to determe the bundary of estimating region and to calculate area under the condition to use the application program for the reserves evaluation.

In this paper, to solve these problems, we performed the block estimator by disjunctive kriging. For the sake of this, first, it is very important to determine reasonably the estimating block size.

We selected the grade and thickness as the main regionalized variables and estimate the variogram for it and then we determied reasonably the estimating block size with due regard to range, scale of drill arrangment map of the reserves evaluation area. During the estimating block size less than range value, it can be satisfied its variance and correlation and also it is reasonable to determine estimating block size with due regard to the scale of drill arrangement map on the estimating area for the convenience of calculation.

1.3. Conditions to estimate reserves

1.3.1. Selection of regionalized variables

Although there are several estimation indices of reserves, among them main indices are grade, thickness and thickness-grade, etc. To select these values as the regionalized variables, they are continious variable or their statistical distribution feature must be fit into the selected method.

1.3.2. Volume weight of ore

The volume weight of ore is proportioned to the grade of ore body in the case which the ore is metal ore. It is good to measure its volume weight, grade and thickness of ore accroding to drills.

1.3.3. Lowest industrial standard

The lowest industrial standard in the respective deposit determine to regard the geological condition, technical and economic condition and mining condition.

1.4. Evaluating process of reserves.

We determined the estimating block size with due regard to the range given from disjunctive kriging estimating process and seperated the evaluating area by that size and estimate disjunctive kriging estimator for each block.

And then, As we used only reserves calculation on the blocks in which the estimators given by progressing the disjunctive kriging estimation are larger than the lowest industrial standard value and we evaluated the total reserves of evaluating area with the method to sum them up.

①It can be calculated the prediction value and conditional probability of the grade and thickness for the estimating blocks by disjunctive kriging estimation.

②With the extracted data, the reserves of each block is calculated then summing up all their values, we can evalute all reserves for the respective ore body.

The volume of respective block ore body V_i is calculated using thickness (M_i ($i = 1 \sim n$)) of area resulting from disjunctive kriging estimation for each block (area S).

$$V_i = S \times M_i \qquad (10)$$

Ore reserves of each block(Q_i) is calculated to multiply the volume of ore body by volume weight (d).

$$Q_i = V_i \times d \qquad (11)$$

Ore reserves multiplied by block conditional probability ($\hat{\Omega}^{DK}[Z(y_i) \geq Z_c]$) resulting from disjunctive kriging estimation for the thickness and it can be caculated ore reserves that is whether equal to or larger than lowest industrial standard.

$$Q_{iC} = Q_i \times \hat{\Omega}^{DK}[Z(y_i) \geq Z_c] \qquad (12)$$

Then the metal reserves of block (P_{iC}) can be calculated as follows

$$C_{iC} = C_i \times \hat{\Omega}^{DK}[Z(x_i) \geq Z_c] \qquad (13)$$

$$P_{iC} = C_{iC} \times Q_i \qquad (14)$$

Where, C_i is the estimated block grade, C_{iC} is the grade that is equal to or larger than lowest industrial standard.

Summing up ore reserves and metal reserves calculated for each block respectively, it calculates the recoverable reserves in study area.

$$Q_C = \sum_{i=1}^{n} Q_{iC} \qquad (15)$$

$$P_C = \sum_{i=1}^{n} P_{iC} \qquad (16)$$

Estimating algorithm of reserves by disjunctive kriging is as Figure 1.

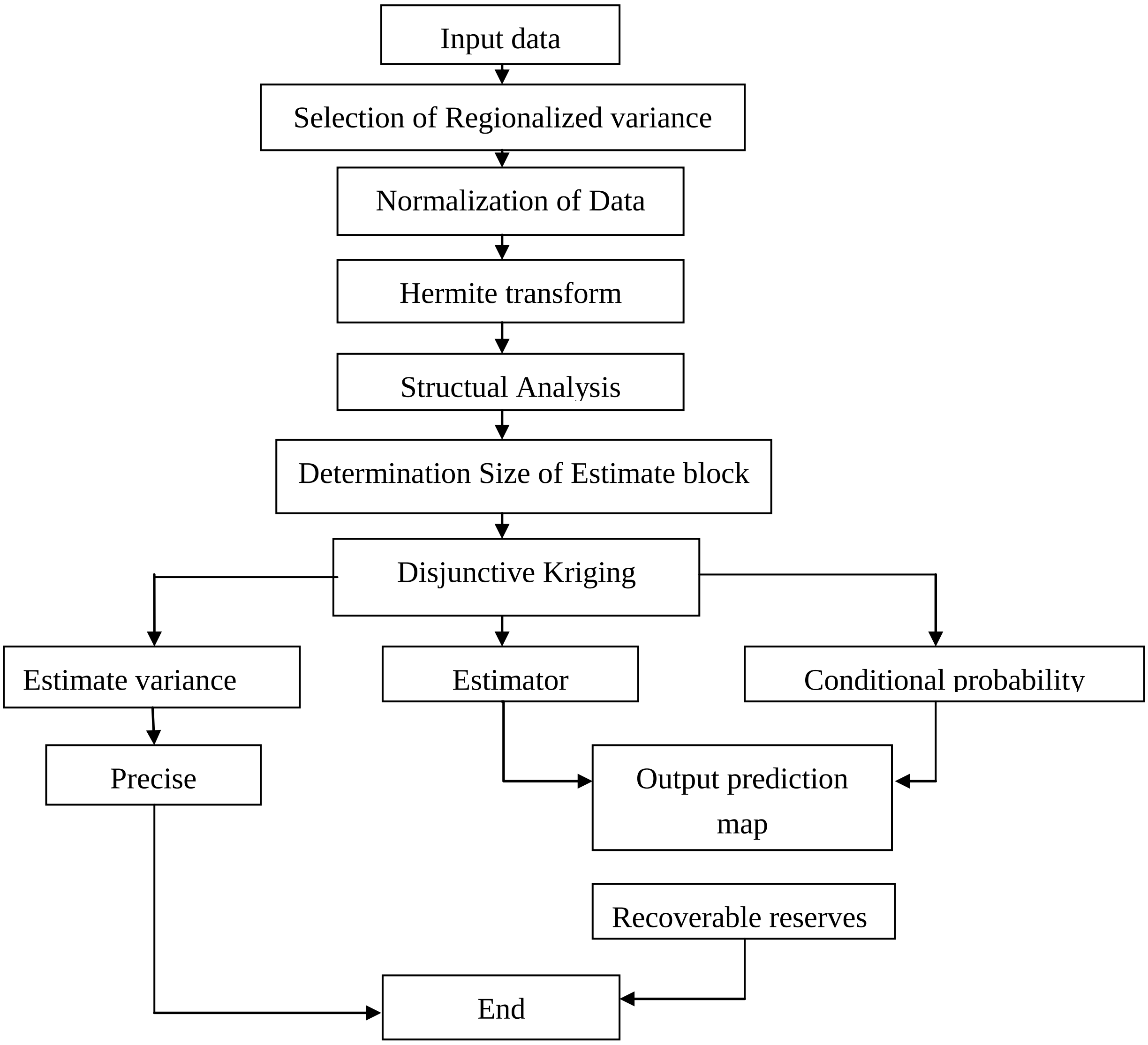

Fig. 1. Estimating algorithm of reserves by disjunctive kriging

2. Conclusion

In this paper, we established one method of the reserves calculation by using the Gaussian disjunctive kriging, which is the most common type of disjunctive kriging.

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