Research Journal of Applied Sciences, Engineering and Technology 4(21): 4227-4236, 2012
ISSN: 2040-7467

Submitted: December 20, 2011 Accepted: April 23, 2012 Published: November 01, 2012

Gravity Anomaly Separation based on Bidimensional Empirical Mode Decomposition

Yao Pei, Yan-Gang Wu and Da-Cheng Jia
College of Geoexploration Science and Technology, Jilin University, Changchun, China

Abstract: Empirical Mode Decomposition is a time-frequency analysis method which can adaptive decomposition of complex signals. This article proposed the bidimensional empirical mode decomposition based on the calculation principle of empirical mode decomposition and the structural characteristics of the regional gravity anomaly. This method can be applied to the separation of gravity anomalies. The intrinsic mode functions of different scales contain various bands of compositions, then obtained the depth of field source by Power spectrum of radial average logarithmic. Compared with the conventional methods, such as the upward continuation method in the potential field separation method, we don't need to set any parameters beforehand. The application shows that in DaolangheDuge area: the multi-scale component based on bidimensional empirical mode decomposition could reflect the anomaly source form from shallow to deep. The field source of local gravity high value in the depth of less than 200 m, The field source of area gravity anomaly in the depth of 500 m, the base form is slope towards the North East which northwest high to southeast low.

Keywords: Bidimensional empirical mode decomposition, gravity anomaly, intrinsic mode function, separation

INTRODUCTION

Gravity anomaly is the superimposition of gravity change which is caused by heterogeneous bodies with different densities under the ground. It contains abundant information of underground geologic structure (Liu *et al*., 2010). We can solve the problems concerning finding the ore or researching the local structure according to gravity anomaly, for example, when researching the oil-bearing structure, sometimes it needs to get rid of the anomaly caused by local structure from Bouguer gravity anomaly because this anomaly always will cover the anomaly caused by ore body or local structure to make it very unobvious (Xiao *et al*., 1983). It is the basic task of gravitational prospecting to extract meaningful ore discovering information through processing, analyzing and making picture of gravity data. For a long term, many scholars have developed the matched filtering method, vertical second derivative method, analytic continuation method, wavelet multi-resolution analysis method and many other methods of data processing and field separation. However, the subject gravity anomaly abstraction has had no basic solution. So the new abstraction method of gravity anomaly is always the key point of research. Huang *et al*. (1998), put forward a new time-frequency analysis method to process non-linear and unsteady signal-EMD (Empirical Mode Decomposition method, EMD for short) (Huang *et al*., 1998). Nunes *et al*. (2003) and some other scholars improved this method and applied it to image processing field and expanded it to the two dimensional empirical mode decomposition method (Nunes *et al*., 2003). Zhou *et al*. (2010) applied one dimensional EMD technique to the profile separation of magnetic field and gravity field (Zhou *et al*., 2010; Zeng and Liu, 2010) and the research of structure partition, igneous rock oil gas prospective area and others got the prospected processing effect. But when processing actual gravity data, the focus is always the research of regional gravity anomaly and the research of bidimensional empirical mode decomposition applied in the regional gravity anomaly processing which is recorded in the form of discrete data is few. In this study, based on the calculation principle of EMD method and according to the structural features of regional gravity anomaly, the author put forward calculation method of bidimensional empirical mode decomposition of regional gravity anomaly which aims to provide new approach and method for gravity anomaly separation.

METHODOLOGY

Bidimensional empirical mode decomposition method: The basic principle of bidimensional empirical mode decomposition is do self-adaption decomposition to complex signal to make it the sum of frequency component of limited number. These components can be

Corresponding Author: Yao Pei, College of Geoexploration Science and Technology, Jilin University, Changchun, China

called IMF (Intrinsic Mode Function, IMF for short). IMF must satisfy these two conditions:

- The sum of the local maximum value and local minimum value must be equal to the number passing the null point or the difference is small at most.
- At any time, the average value of upper envelope defined by local maximum value and lower envelope defined by local minimum value is zero.

In essence, this method is to differentiate internal oscillation function according to its characteristics and scale in the data and decompose the data correspondingly (Song and Zhang, 2001). The frequency of IMF component after decomposition is arranged from the highest to the lowest one, that is to say, the first decomposed IMF component has the highest frequency and the last decomposed IMF component has the lowest frequency and the residue component is usually a monotone function which only has a extreme point and represents the tendency of the original signal. Bidimensional empirical mode decomposition method does the steady processing of the data according to the scale characteristics of the signal itself. Theoretically it can be decomposed into the signal of any type. Compared with Fourier analysis depending on prior function basis, wavelet analysis and other methods, EMD needs not to preset the primary function and is a self-adaptive time frequency localization multiscale analysis method (Huang and Wu, 2004).

Bidimensional empirical mode decomposition algorithm: According to the basic principle of the above method, BEMD is applied to do the multi-scale decomposition to the data. Considering the convenience of implementation and efficiency, the decomposition and screening procedures are as follows:

Step 1: After read-in of data array, extract algorithm based on certain effective extreme point (morphological algorithm is used in this study), confirm the local extreme point (including maximum value and minimum value) of data $f(x, y)$; x = 1, …, M; y = 1, …, N.

Step 2: Do surface fitting to all maximum value point and minimum value point of $f(x, y)$ respectively, to form upper envelope surface $u_{max}(x, y)$ and lower envelope surface $u_{min}(x, y)$. Make sure that all the points of $f(x, y)$ are located between upper and lower envelope surfaces. Surface fitting is the key of implementation of BEMD.

Step 3: Confirm the average value of upper and lower envelope surfaces:

$$m(x, y) = [u_{min}(x, y) + u_{min}(x, y) / 2 \tag{1}$$

Step 4: Solve and take the difference value between $f(x, y)$ and average value of upper and lower envelope $m(x, y)$:

$$h_l = (x, y) = f(x, y) - m(x, y) \tag{2}$$

Step 5: Judge whether $h_1(x, y)$ accords with IMF component condition or not. If the condition is satisfied, it is the first IMF; If the condition is not satisfied, screening of the above procedures is repeated K times until the result $h_{1k}(x, y)$ after screening satisfies the definition of IMF, then it is the first IMF component:

$$IMF_1 = h_{1k}(x, y) \tag{3}$$

Step 6: Use the difference between $f(x, y)$ and IMF_1 as the new data to repeat the above process and then the of the second IMF component IMF_2 can be obtained. When IMF component IMF_n or residue R is less than pre-established decomposition threshold or has become monotone function, then the process ends. Through continuously taking out the maximum value and minimum value BEMD method connects the average value of upper and lower envelopes and decomposes the original signal into the sum of n IMF components and residue R, that is, complete the process of multi-scale decomposition of data:

$$f(x, y) = \sum_{j=1}^{n} IMF_j + R \tag{4}$$

In the formula, IMF_j is IMF component; R is residual component which is a monotone function, contains a relatively large quantity of energy and represents the enrichment tendency of regional elements. Because IMF component is the wave of different characteristic scales which is got after decomposition according to the features of original signal, this method is not only suitable to decomposition of linear data, but also suitable to decomposition of nonlinear discrete data, which provides theoretical basis for its application in two dimensional image processing.

The terminal condition of BEMD is still not very clear at present. According to decomposition threshold standard of screening stopping confirmed by Huang *et al*. (1998), it can be realized by limitation of Standard Deviation (SD):

$$SD^2 = \sum_{x=0}^{X}\sum_{y=0}^{Y}\left[\frac{\left|\left(h_{k-1}(x, y) - h_k(x, y)\right)\right|^2}{h_{k-1}^2(x, y)}\right] \tag{5}$$

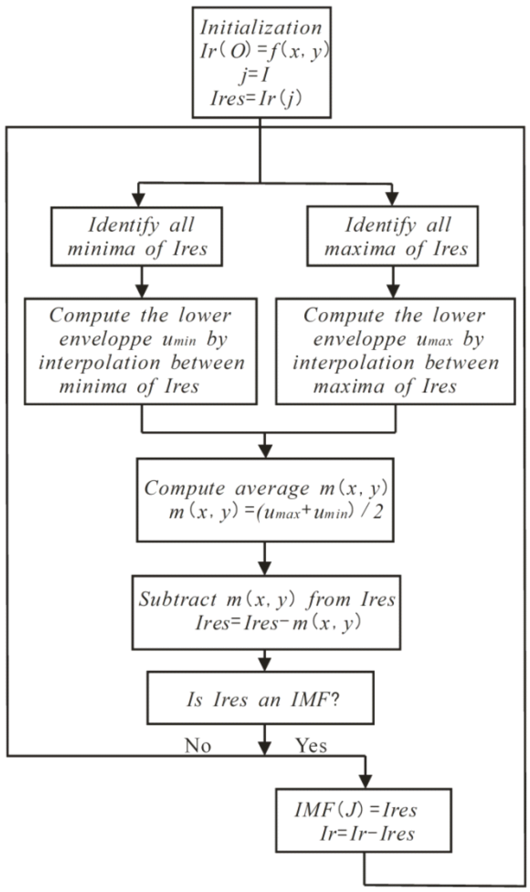


Fig. 1: The sifting process

There is no fixed standard of confirmation of SD value and the general choice is between 0.2 and 0.3 and its value has the direct influence to the decomposition process of BEMD. The smaller the set SD value is, the bigger the number of decomposed IMF is, but the time taken in decomposition process will be rapidly increased (Li *et al*., 2009). Its flow chart is shown in Fig. 1.

Spectral analysis method to determine the depth of field source: Bidimensional Empirical Mode Decomposition (BEMD) fully takes the relation between discrete regional Bouguer gravity data into consideration. It decomposes Bouguer gravity anomaly into IMF component of different scales. The depth of field with different scales can be got through power spectrum analytical method:

- Do Fourier transform to IMF component and then calculate radial logarithm power spectrum,

  Among them: *A* is the constant which relates with volume, residual density and other parameters, *r* is the radial frequency, *h* is the burial depth of source of the field.

$$\ln E(r) = \ln A^2 - 2hr \quad (6)$$

- lnE (r) and *r* has linear relation. Its straight slope is *-2 h*. Determine burial depth of source of the field according to radial logarithm average power:

$$h = \frac{\ln E(r_1) - \ln E(r_2)}{4\pi(r_2 - r_1)} \times \Delta \quad (7)$$

where, Δ is the dot pitch and *h* which is got by calculation is with the unit of Δ.

Table 1: Model parameters of sphere

Parameter	Ball 1	Ball 2	Ball 3	Ball 4	Ball 5	Ball 6
X (m)	20	20	-20	-20	0	0
Y (m)	20	-20	20	-20	0	0
Depth (m)	6.5	6	6	7	7	40
Radius (m)	4.5	4	4	4.5	5	20
Density (g/m^3)	1	1	1	1	1	0.8

Bidimensional empirical mode decomposition model test: Build a model to test and verify the decomposition result of bidimensional empirical mode decomposition to superposition gravity field. Because this method is based on extreme point envelope, the decomposition effect is not so good under the condition of too few extreme points. Especially when the extreme point is less than or equal to one, it is impossible to do calculation. When there are many extreme points and the calculation field is relatively big, the calculation effect of this method gets better obviously. The model is composed of 6 balls. The ball with the relatively big deep part imitates regional anomaly and the other five balls with the relatively small deep part are distributed in the center and the four corners to imitate local anomaly. The parameters of each model are shown in Table 1. The dot spacing and line distance are all 1 m and its gravity superposition anomaly is shown in Fig. 2.

From the radial average logarithm power spectrum of theoretical model (Fig. 3), it can be seen clearly that energy spectrum is composed of two frequency ranges, that is, the regional anomaly energy is mainly the low frequency and the local anomaly energy is mainly the medium and high frequency range. These two parts of anomaly have different energy spectrum distribution characteristics. Therefore, the separation of anomaly is feasible. When using the bidimensional EMD to decompose the model superposition anomaly, model body is relatively simple, so only an IMF component and residual R component are decomposed. The first

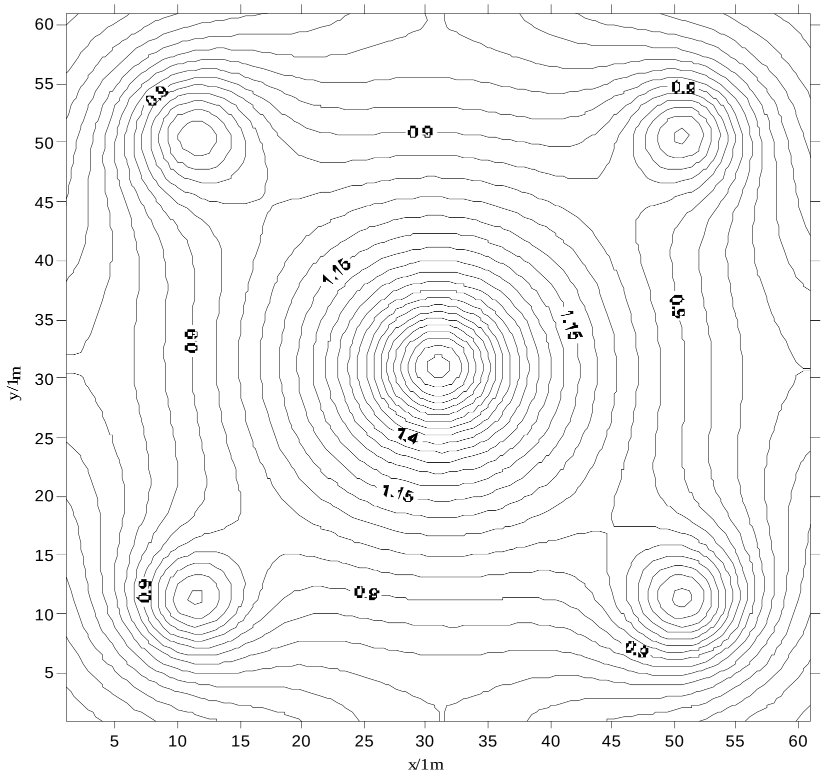


Fig. 2: Superimposed anomaly of model

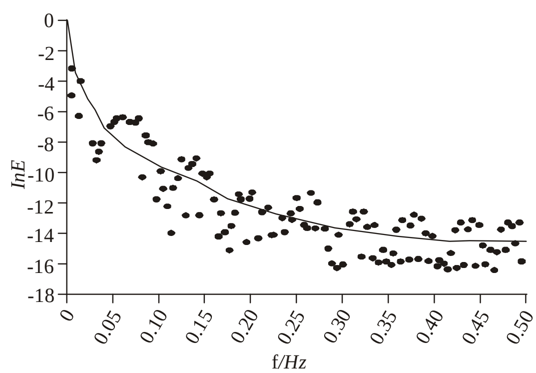
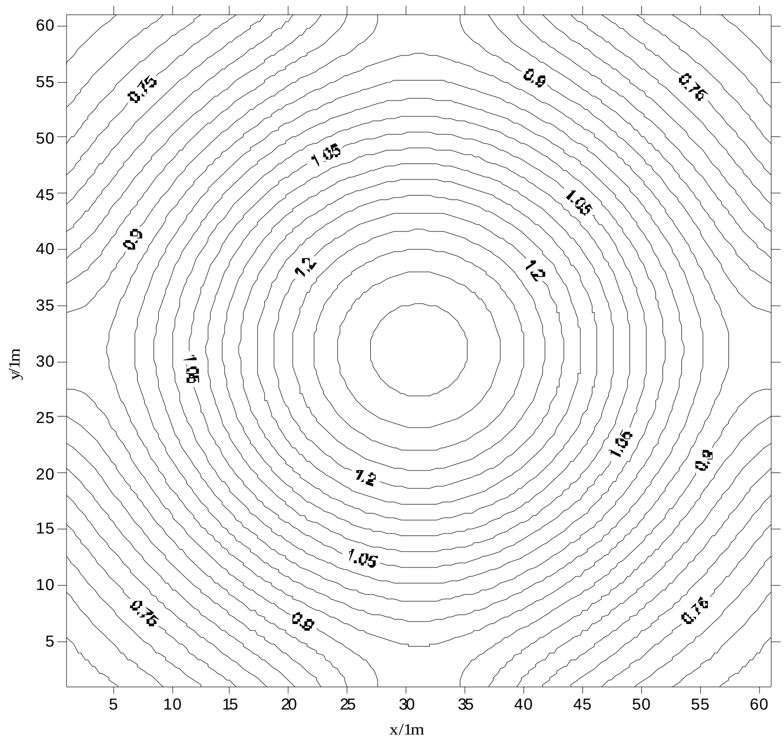


Fig. 3: Power spectrum of radial average logarithmic of model

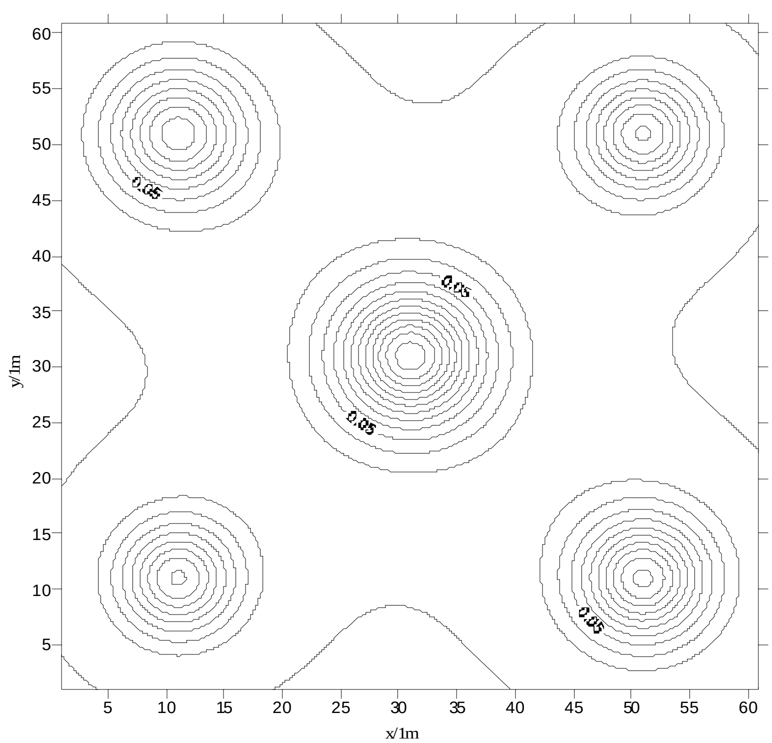
decomposed IMF component is seen as local anomaly. The difference between model superposition anomaly and local anomaly is regional anomaly caused by the large ball in the deep part and it is represented by residual component R (Fig. 4). Compared with the result (Fig. 5) upward continuation of 10 dots pitch, the effect of using bidimensional empirical mode decomposition method to abstract local anomaly is better and especially the anomaly of the globule in the center of the model is not covered because of the big regional anomaly. The decomposition of regional anomaly high frequency information caused by the big ball is more thorough than extension method. There is no obvious distortion of anomaly boundary. Obviously, the effect of bidimensional empirical mode decomposition to decompose anomaly is better than the traditional prolongation method (in order to reduce the edge loss and use the actual measurement data to do geological interpretation, it is always needed to do expanding edge processing to actual measurement data to satisfy the needs to the follow-up processing).

EXPERIMENTAL RESULTS AND ANALYSIS

Daolang of Bordered Yellow Banner and Duge are both located in the center of the Inner Mongolia Autonomous Region, which is in the central region of Inner Mongolia grassland. In terms of tectonics, it is in the middle section of north rim of North China plate, to the south of Xar Moron River fracture. This area is influenced by the magmatism of the north rim of North China craton of Yanshan period. There are many igneous rocks on the earth’s surface. It can be seen from the Bouguer gravity anomaly contour map of the research area (Fig. 6) that the northeast gravity high trap whose anomaly is mild, anomaly axis is in the northwest of

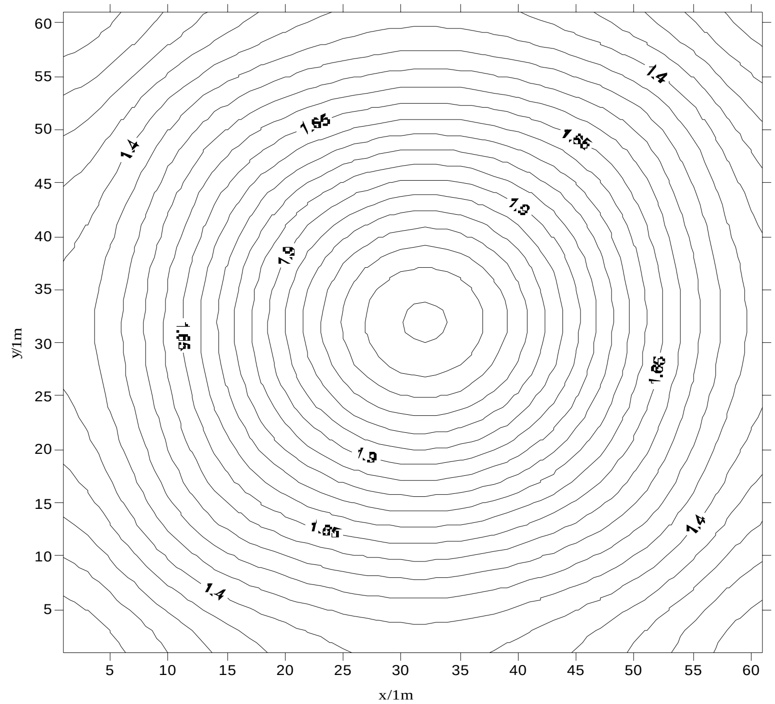


(a)

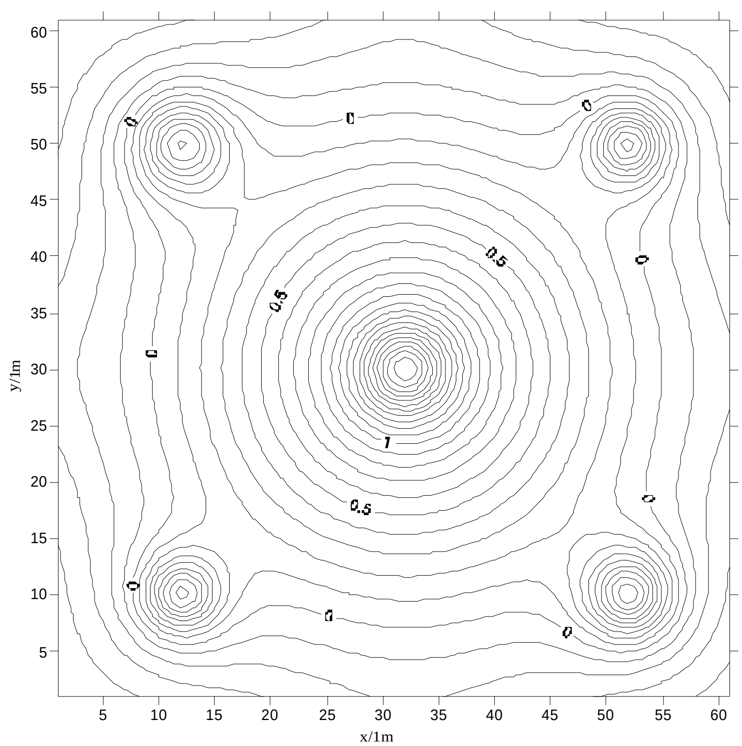


(b)

Fig. 4: Result of BEMD: (a) Regional field abstracted by BEMD; (b) Local field abstracted by BEMD



(a)



(b)

Fig. 5: Result of upward continuation: (a) Regional field abstracted by the traditional prolongation method; (b) Local field abstracted by the traditional prolongation method

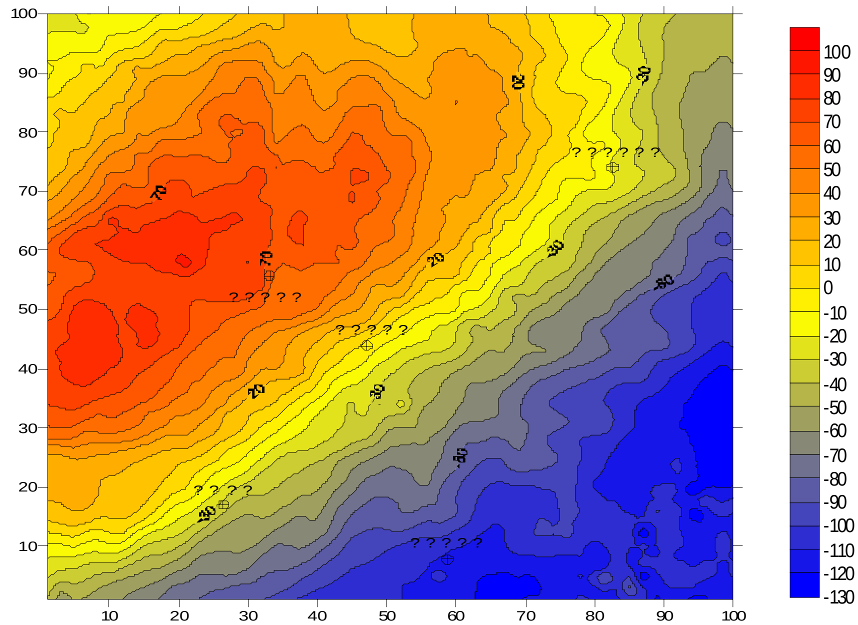


Fig. 6: Bouguer gravity anomalies in study area

testing area, anomaly value gradually decreases from the axis of gravity high trap to the two sides of northwest and southeast and the southeast of the research area is the minimum value. The data of research area is 100×100, dot pitch and line distance is both 50 m, the minimum value of Bouguer gravity anomaly is -133.614 g.u and the maximum value is 95.190 g.u. and the average value is -14.6671 g.u. Based on Bouguer gravity anomaly data of research area, do bidimensional empirical mode decomposition to it to get more and richer physical geographical (geological) information which is of great importance to circle the ore body, igneous rock and local structure, understand the abnormal condition caused in the different underground depth and position and do the initial geological interpretation of multi-scale decomposition result.

Figure 7 is the Bouguer gravity anomaly radial logarithm power spectrum of Daolang and Duge area. Three wave bands whose slope has obvious change can be divided in the power spectrum curve and they are 0 0.08, 0.08~0.25, 0.25 0.5 Hz, respectively in order. It shows that gravity anomaly is at least composed of 3 different scales. Using bidimensional empirical mode decomposition method to do data decomposition can get 3 IMF components and residual component, that is to say, by using this method we can decompose the original Bouguer gravity anomaly data into 4 different scales. It shows that the precision of bidimensional empirical mode decomposition is higher than the result we got from the power spectrum.

There are relatively big differences among the scales of each IMF component, so the physical geographical

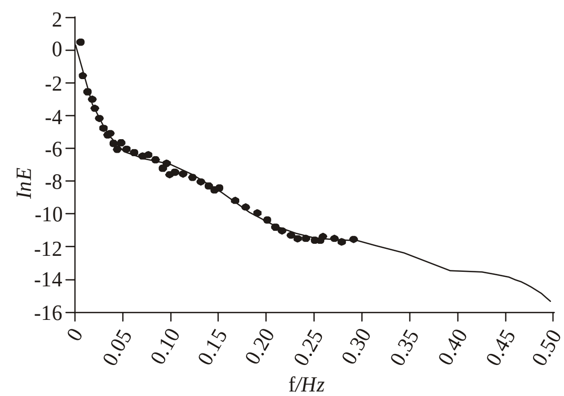
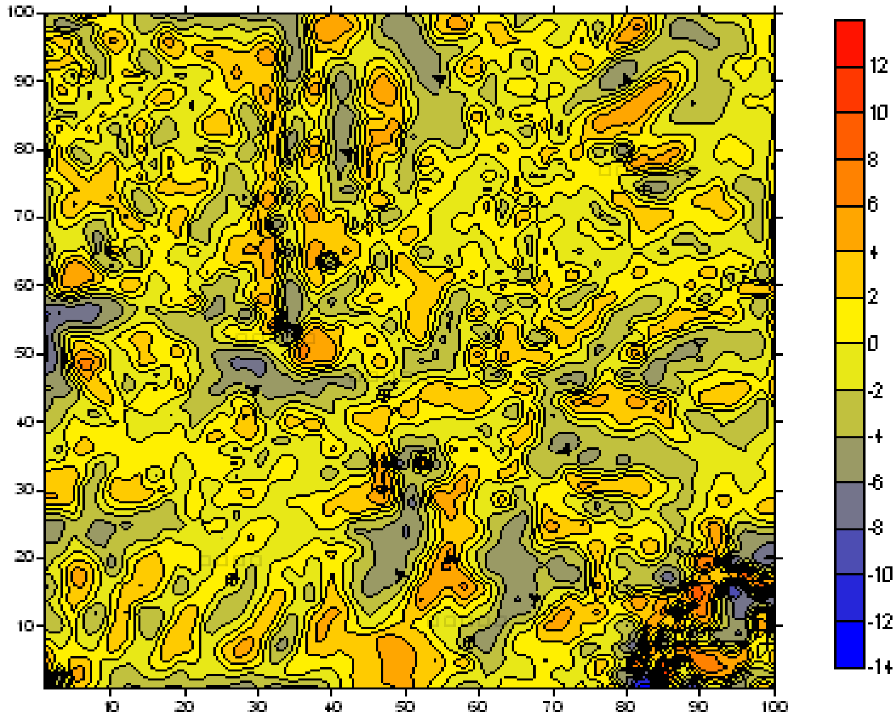


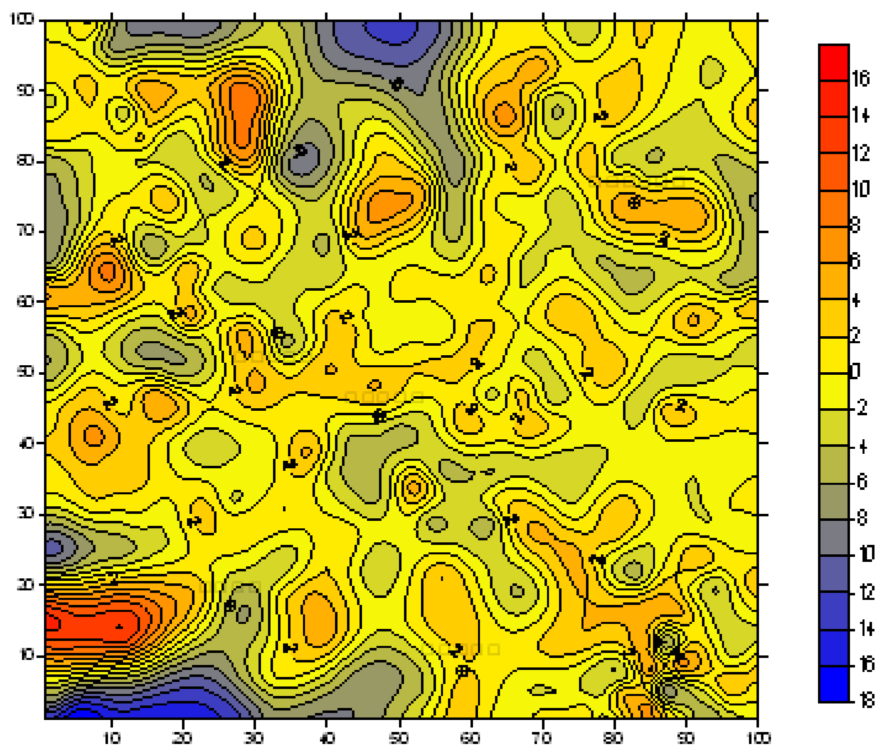
Fig. 7: Power spectrum of radial average logarithmic of study area

meaning among different components is different. IMF_1 component (Fig. 8a) is small scale component, anomaly form is relatively untidy and high and low density form mix together, contour lines distribute intensively with string anomaly with unobvious direction. It mainly reflects the local anomaly of research area. It can be known from the calculation of radial logarithm power spectrum that similar depth of field of source of IMF_1 component is 99.7 m. It mainly reflects the superficial ore body in the underground 100 m of research area, local structure and density uniformity caused by active jamming (steel and other objects with high density left by ore mining and other activities).



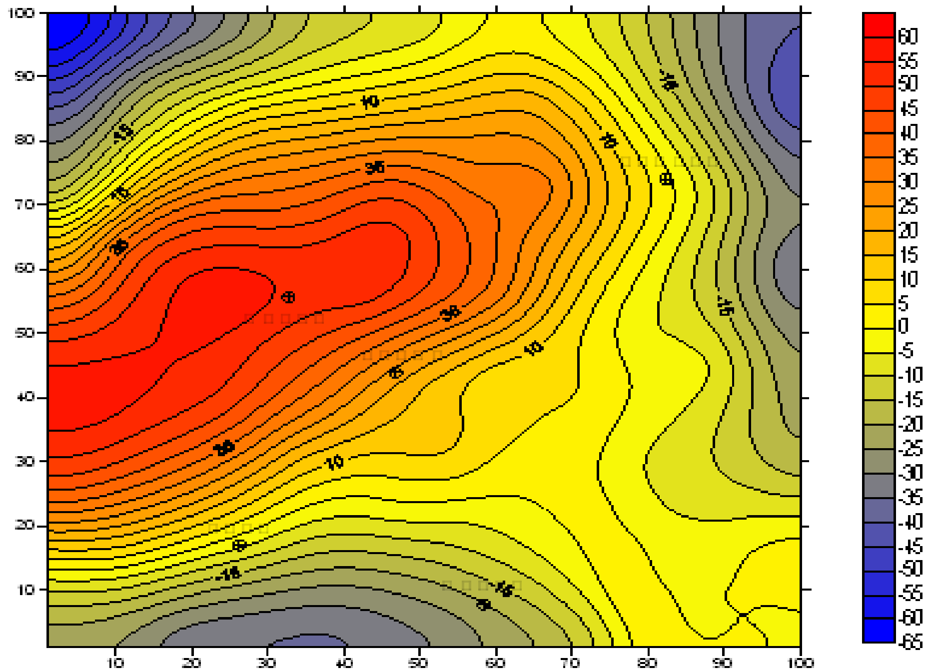
100
90
80
70
60
50
40
30
20
10
10
20
30
40
50
60
70
80
90
100
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14

(a)

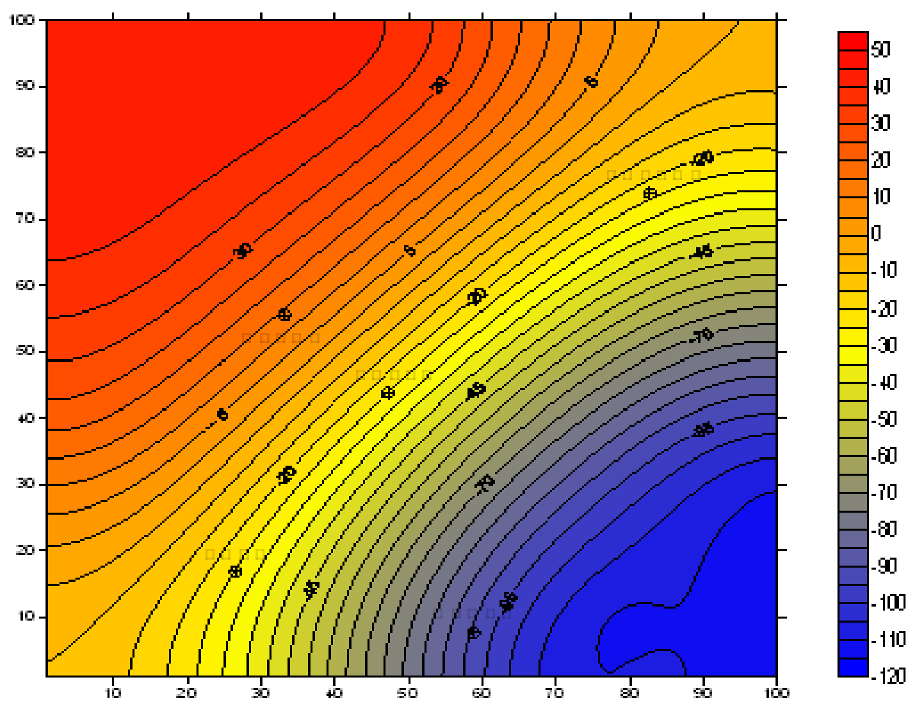


100
90
80
70
60
50
40
30
20
10
10
20
30
40
50
60
70
80
90
100
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18

(b)



(c)



(d)

Fig. 8: Bidimensional empirical mode decomposition of study area: (a) Bouguer gravity anomaly IMF_1 component; (b) Bouguer gravity anomaly IMF_2 component; (c) Bouguer gravity anomaly IMF_3 component; (d) Bouguer gravity anomaly residual R component

IMF_2 component (Fig. 8b) scale is slightly bigger than IMF_1 component. The anomaly characteristics shows that intensive gradient in the northeast encircles many gravity high traps with different sizes. The positive anomaly is mainly distributed near the Daolang and Duge which are in the west of research area and the aggregation first appears the direction of northeast which is identical with igneous rocks of large area which expose on the earth surface. The similar depth of field of source of IMF_2 component is 200 m, that is to say, the main object of local anomaly is within 200 m and the fractures in the area also mainly extend to this depth. It can be seen from the geologic map of testing area that there are mainly fag-medium typed, medium fag biotite granite in the Yanshan period. The range of density change of exposing granite is 2.4 3.1 g/cm^3. In the residual field the local gravity high trap phenomenon is possibly caused by many minerals with high density within the rock which have relatively higher density than surrounding rock

IMF_3 component (Fig. 8c) is large scale component. Its area of positive and negative anomaly is big and anomaly change becomes mild obviously. There is basically no distortion in the stair gradient contour line and it is shown as a gravity high antiform. Seen from anomaly characteristics, there is relatively big difference between IMF_3 component and the first two *IMF* components. It mainly reflects the deep area field of research area. It can be know from power spectrum that the similar depth of field of source of IMF_3 component is about 500 m. It is inferred that the geologic body with high density, big thickness and strong regularity in the northeast and center of research area is the subject which causes the gravity positive anomaly of this research area.

The similar depth of field of source of residual R component (Fig. 8d) is 700 m. It shows the northwest positive and southeast negative gravity field characteristics and reflects the basement form of research area is mild gradient slope which has the direction of northeast and is high in the northwest and low in the southeast.

CONCLUSION

So far there is still no method which is better than any other method under any condition. Bidimensional empirical mode decomposition does not depend on primary function. Based on the features of the signal itself, it does multi-scale decomposition to gravity and magnetic data to make it can be completely applied in processing the complex regional gravity data and to get more and richer physical geographical (geological) information. It is of great importance to circle the ore body, igneous rock and local structure, understand the abnormal condition caused in the different underground depth and position and do the initial geological interpretation of multi-scale decomposition result. The result of Bouguer gravity anomaly decomposition of Daolang and Duge area shows that: multi-scale decomposition based on bidimensional empirical mode decomposition can preferably reflect the form of abnormal source from the shallow to the deep, the corresponding depth of field of source of the local gravity high value of this area is mainly within 200 m, the similar depth of field of source of geologic body which causes the gravity anomaly is about 500 m, basement form is mild gradient slope which has the direction of northeast and is high in the northwest and low in the southeast. It is more obvious in the deep part and shows the stair gradient in the direction of northeast. It is stated that the upper and lower layer of the field of source underground has both independence and inheritance to some extent. Bidimensional empirical mode decomposition of gravity field can get more information and richer physical geographical (geological) meaning than the previous analytic continuation and other traditional field decomposition methods.

REFERENCES

Huang, N.E., Z. Shen and S.R. Long, 1998. The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis. Proc. R. Soc, London, 454: 903-995.

Huang, N.E. and Z.H. Wu, 2004. A study of the characteristics of white noise using the empirical mode decomposition method. Proc. Royal Soc. London, 460: 1597-1611.

Li, X.K., L. Xie and Y. Qin, 2009. Underwater target feature extraction using Hilbert-Huang transform. J. Harbin Eng. U., 30: 542-546.

Liu, Z., M.C. Liu and W. Wei, 2010. Gravity anomaly separation based on cellular neural network. J. China U. Petrol., 34: 57-66.

Nunes, J.C., O. Niang and Y. Bouaoune, 2003. Bidimensional empirical mode decomposition modified for texture analysis. Proceedings of the 13th Scandinavian Conference on Image Analysis, Heidelberg, pp: 171-177.

Song, P.J. and J. Zhang, 2001. The application of two-dimensional EMD to separating contents of oceanic remote sensing images. High Techn. Lett., 9: 62-67.

Xiao, J.Y., G.F. Zhou and Z.M. Lin, 1983. The Explained Manual of Gravity Exploration Information. The Geological Publishing House, Beijing, pp: 1-475.

Zeng, Q.Q. and T.Y. Liu, 2010. A potential field separation method based on empirical mode decomposition. Oil Geoph. Prospect., 45: 914-917.

Zhou, W.N., S.F. Zeng and X.J. Du, 2010. Gravity anomaly separation based on empirical mode decomposition. Global Geol., 29: 495-502.