Experiment and interpretation of geomorphological detection by multi-beam sonar in Huguang-yan Maar Lake

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Abstract. The Huguangyan Maar Lake is caused by a volcanic eruption. The original sediments at the bottom of the lake are natural yearbooks for the evolution of the earth's climate and environment. A multi-beam sonar technique is used to scan the full coverage on the lake surface to get fine samples of echoes from the lake bottom. The information of the bathymetric data of the lake bottom is accurately described and the results of three-dimensional geomorphology imaging are given. The results show that the lake is divided into two parts, east and west, by a north-south underwater volcanic wall, and the maximum depth of water is over 22 meters. We apply a texture feature extraction method based on multi-scale fractal dimension to describe the characteristics of the sediments and roughness. Multi-scale fractal dimensions algorithm is used to extract waveform characteristics of depth samples in different directions. General distribution of sediment at the bottom of the lake is distinguished by the width of multi-scale fractal spectrum. The results obtained can be helpful for the estimation of the physical properties of sediments.

1 Introduction

The acoustic characteristics of sediment can be studied by means of acoustic reflection and acoustic scattering [1, 2]. The multi-beam system can not only obtain information on the topography of the floor but also collect information on the intensity of echoes from the floor, which made it possible to simulate the geological characteristics by acoustic information [3, 4]. At present, the classification method of sediments mainly includes the following types of methods: inversion of acoustic parameters of the floor, classification by statistical characteristics, and method of manual sampling, etc.. In this article, we use the multi-beam bathymetric system to obtain bathymetric data with 100% full coverage of the lake floor by means of airborne scanning measurements. Multi-scale fractal dimensions algorithm [5, 6, 7] is used to extract waveform characteristics of depth samples in different directions. Width of fractal spectrum of different regions shows different characteristics. Experimental results show that this method is effective for sediments classification of lake.

2 Detection by multi-beam sonar in Huguangyan Maar Lake

2.1 Background

The English "Maar" comes from the Latin "Mae", meaning swamp or lake. There are two most typical

lakes in the world; one is located in Huguangyan, Zhanjiang city, in China and another in the Eiffel region of Germany. Huguangyan Maar Lake covers an area of 2.3m². The lake is originated from the volcanic eruption 160,000 years ago. The study of the topography of the lake helps to understand the formation mechanism of the lake and inversion of its formation process. At the same time, it is helpful for the environmental management and protection.

2.2 Bathymetric system of multi-beam sonar

2.2.1 System composition

The 2024 multi-beam bathymetric transducer is applied in the system. Detecting system layout is as Fig.1.

Fig. 1. System layout.

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The 2024 multibeam system is a bathymetric device based on the fifth-generation produced by R2SONIC. The Sonic 2024 system consists of three main components: the transmitting array, the receiving array, and the sonar interface module (SIM).

2.2.2 System parameters

The 2024 multi-beam bathymetric system can select more than 20 frequencies online within a range of 200 to 400 kHz. At 400kHz frequency, its transmission beam width is 0.5° and the receiving beam width is 1° . The 2024 flexibly selects the appropriate coverage angle according to the actual operating conditions within a range of 10° to 160° . The transducer has a maximum bathymetric range of 500m. There are 256 receiving beams for each launch of the system, and the beam interval can be set to equidistant and equiangular mode.

2.2.3 Measurement results

The water depth data are obtained by using multi-beam sonar by scanning the full coverage of the lake. The pseudo-color image based on bathymetric data is shown in Fig. 2(a). The black lines in the (a) describe the position of scanning samples used to calculate the fractal dimension. The underwater 3D-surface model of Marr lake is shown in Fig.2(b). Clearly, the lake is divided into two parts by a north-south underwater volcanic rock wall. The West Lake has a large area and is the main part of the lake. The maximum water depth exceeds 22m. East Lake has a relatively small area and a maximum depth of no more than 10m. The volcanic rock walls in the northern part of the lake are shallow, and some rock walls will expose the water surface.

Fig. 2. Underwater 3D topography of Marr lake.

For describing the characteristics accurately of the sediments and roughness, in the section 3, multi-scale

fractal dimensions algorithm is used to extract waveform characteristics of depth samples in different directions.

3 Multi-scale fractal dimensions algorithm

Multi-scale fractal dimensions [8] are singular geometry with several number of non-uniform fractal dimensional distributions, which are superimposed by different fractal subsets. By this mean, we can understand the fine structures inside the fractal layers. Here, a sample from a multi-beam scanning result is represented by x_k , and x_k is a series of length N . The profile of the sequence x_k is defined as

$$Y(i) = \sum_{k=1}^i (x_k - \bar{x}), i = 1, \dots, N \quad (1)$$

Here $\bar{x}$ is the mean value of x_k . Divide the $Y(i)$ into nonoverlapping segments, $N_s = \text{int}(N/s)$, the number of data per segment is s . Calculate the local trend of $2N_s$ segment by least-square fit of the series. The variance is determined by

$$F^2(v, s) = \frac{1}{s} \sum_{i=1}^s \{Y[(v-1)s + i] - y_v(i)\}^2, v = N_s + 1, \dots, 2N_s \quad (2)$$

The function $y_v(i)$ is the fitting polynomial in segment v . The q th order fluctuation function is calculated by average over all segments.

$$F_q(s) = \left\{ \frac{1}{2N_s} \sum_{v=1}^{2N_s} [F^2(v, s)]^{q/2} \right\}^{1/q} \quad (3)$$

In the equation (3), q is order of the statistical moment, which can represent the degree of multiple fractal inhomogeneity. $F_q(s)$ is an incremental function about s and q and satisfy the following rules

$$\left\{ \frac{1}{2N_s} \sum_{v=1}^{2N_s} |Y(vs) - Y((v-1)s)|^q \right\}^{1/q} \sim \quad (4)$$

Characteristic function of fractal dimension is defined as

$$\tau(q) = qh(q) - 1 \quad (5)$$

The function $\tau(q)$ is characteristic function. If the function is about the convex function of τ , the sample sequence studied has multiple fractal features. $H(q)$ is Hurst index of wave function, multi-scale fractal spectrum is defined as

$$f(\alpha) = q[\alpha - h(q)] + 1, \quad (6)$$

where, $\alpha(q) = h(q) + qh'(q)$

The width and maximum of the fractal dimension spectrum can measure the heterogeneity of multi-scale fractals of the sample data. That is, the greater the W , the greater the heterogeneity the waveform.

$$\begin{cases} W = \alpha_{\min} - \alpha_{\max} \\ f(\alpha)_{\max} = f(\alpha_0), \alpha \in [\alpha_{\max}, \alpha_{\min}] \end{cases} \quad (7)$$

3 Interpretation of geomorphological detection

Time series samples covering different latitude and longitude are obtained by sailing multi-beam sonar from west to east. Here, we use samples from the larger west lake to interpret relationship between the sediment characteristics and fractal dimension. The path of multi-beam scanning to obtain samples is shown in the Fig.2(a). Multi-scale fractal features are calculated by samples from sonar. The number of samples is 260, 460, 560, 960, 1160, and 1360 in the order, which come from different locations on the lake. The seabed geology in these sample areas is completely different. The composition of the seabed in these sample areas is separately hard rock, fine sand, or mud. Fig.3 (a) and (b) give characteristic functions $\tau(q)$ and Hurst index $H(q)$ of six sample sequences, respectively. $\tau(q)$ is the convex function of τ . The results show that the sample sequence has multiple fractal dimension characteristics. Multi-scale fractal spectrum is given in Fig.3(c). Width of spectrum calculated by 1400 samples of full coverage is illustrated in (d).

From Fig.3(c) and (d), obviously, we can see that the multi-scale fractal dimensions of different regions are quite different, and the trend of the curve is different. This is due to the difference structure in the bottom of the lake. Based on actual sampling results, powdered sand samples are mainly distributed in the northwest, southwest, and east of the west lake near the volcanic rock wall. In these areas, the content of sediments changed significantly, and the content of silt and clay decreased sharply. In these regions the roughness of the floor is strong. That is why the fractal spectrum is so broad in these regions. The content of silt and clay increased with the increase of water depth, while the sand content in the surface sediments of Maar lake decreased rapidly with the increase of water depth. This is the reason that the fractal spectrum of samples in these regions is narrow and has random fluctuations. Based on this result, it is necessary to use block technology to extract multiple fractal dimensions, which can helpful for more detailed of the lake bottom.

(a) Characteristic functions of 6 samples

(b) Hurst indexes of 6 samples

(c) Multi-scale fractal spectrum of 6 samples

(d) Fractal spectrum width of 1400 samples

Fig. 3. Multi-scale fractal dimensions of differe samples (the order $q=-5:0.1:5$).

4 Conclusions

Multi-beam can give the floor shape and depth data of lake, but it is difficult to accurately determine actual structure, and it is not possible to conduct a comprehensive and detailed qualitative analysis of the sediment. On the results of multi-beam imaging, multi-fractal dimension method is applied to the classification of the lake floor. Multiple fractal spectrum can reflect the complexity of the sample waveform in the fractal structure. The width of the fractal spectrum reflects the degree of heterogeneity of the probability measure distribution in the fractal structure, thus can comprehensively describe different regions and different local conditions. It is effective to classify sediment of the lake floor with different complexity and different regular distribution by using this algorithm.

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